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Loss Control Management in the Kraft Pulping Industry

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Because spills and losses of process materials are unavoidable consequences of production processes, and because the processes comprising the production of chemical wood pulp use large amounts of water to transport heat, chemicals and product through the processes, there is a need for a management strategy and system to control these intermittent spills and losses. In order to develop feasible strategies, examination and characterization of process effluents from many kraft pulp mills and investigation of existing loss control systems in the industry were conducted. Dynamic computer modelling, using data obtained from monitoring process effluents, was employed to illustrate the utility of this technique to arrive at various loss control strategies for particular process configurations. The installation of a loss control system for other than environmental reasons should show a return on investment. Examples were presented, using data obtained from the monitoring effort, of the net economic benefit which may accrue from recovery of chemicals and organic solids. A loss control strategy was developed for the pulping, pulp washing, and chemical recovery areas of a large kraft pulp mill. The strategy was implemented and operated in the existing spill control system of the mill and control was successfully effected utilizing a digital computer. In addition to managing process losses, the direct digital control system also allowed gathering, processing and managing data obtained from the sensors monitoring the system.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods are used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report is concerned with the development of loss control strategies for the kraft chemical pulping industry and the demonstration of direct digital control, using a process computer, in a loss control management system. The results of the project can be applied in the cyclic process of chemical pulp production by those industry personnel responsible for process control and air and water emission management to effect the control and recovery of process spills and losses. For further information on the subject, contact the Food and Wood Products Branch of the Industrial Environmental Research Laboratory, Cincinnati, Ohio.

David G. Stephan
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Industrial Environmental Research Laboratory
Cincinnati

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CONTENTS

Foreword.. iii

Figures... v

Tables.. vii

Acknowledgement... ix

1. Abstract... 1
2. Scope and Objectives... 3
3. Summary of Findings.. 6
4. Review of Pulp Mill Loss Control Strategies.................. 14
5. Mill Surveys and Analysis.................................... 30
6. Development of Loss Control Strategies....................... 75
7. Loss Control Economics....................................... 128
8. Application of Loss Control Strategy at Brown Company....... 135

BEGIN LAST LINE OF TEXT
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PAGE NUMBER
EPA-287 (Cin.)
(4-73)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

FIGURES

Number Page

4.1 Kraft pulping and chemical recovery closed cycle process....... 15

4.2 Schematic of spill control and recovery system at 1000 tpd kraft mill.. 22

4.3 Schematic of spill control system at an unbleached kraft mill.. 26

5.1 BOD_5 vs TOC for weak black liquor samples.................... 33

5.2 Linearity of TOC response weak black liquor added to mill effluent.. 35

5.3 Linearity of TOC response washer filtrate added to mill effluent.. 35

5.4 Linearity of conductivity response lime mud weak wash added to mill effluent.. 36

5.5 Automatic sampler.. 40

5.6 Sampling location schematic - Brown Company.................. 42

5.7 Sampling location schematic - Crown Zellerbach Company......... 43

5.8 Salt dilution techniques for flow measurement.................. 45

5.9 Range of parameter values - Brown Company.................... 45

5.10 Range of parameter values - Crown Zellerbach Company........... 46

5.11 Sodium vs Conductivity - Brown Company.................... 50

5.12 TOC vs Conductivity - Brown Company....................... 52

5.13 Conductivity sampling/Monitoring scheme...................... 56

5.14 Sodium monitor flow schematic 57

5.15 Original sodium monitor sampling system...................... 60

5.16 Modified sodium monitor sampling system...................... 60

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-78)

5.17 Sodium Monitor Chart.. 63
5.18 Instrument Color vs true color.................................. 68
5.19 Influence of suspended solids on instrumental color measurement.. 70
6.1 Sump pump logic.. 78
6.2 Recovery pump logic.. 78
6.3 Schematic representation of Models A and B.................... 79
6.4 Schematic representation of Models C and D.................... 80
6.5 Printout of Model A results.............................. 98-105
6.6 Printout of Model B results...............................106-101
6.7 Printout of Model C results...............................112-119
6.8 Printout of Model D results...............................120-127
6.9 Schematic representation of Intervention Analysis.............. 90
6.10 Intervention analysis of time series........................... 94
7.1 Spill recovery economics.......................................129
7.2 Example calculation minimum recoverable solids.................131
8.1 Schematic of Brown Co. Loss control strategy system............137
8.2 Schematic evaluation of Brown Co., Spill tank..................140
8.3 Schematic of LCS hardware arrangement..........................142
8.4 Computer and pheripheral equipment.............................147
8.5 Foreground program initialization.........................155-156
8.6 General structure of executive program....................157-163
8.7 General structure of error analyzing routines.............165-166

TABLES

Number Page

4.1 Recommended Size of Liquor Storage Tanks.......................... 17

5.1 Sample Sources... 31

5.2 Weak Black Liquors... 34

5.3 Illustrative Analytical Results.. 38

5.4 Flow Measurements.. 47

5.5 Brown Company Regression Equations...................................... 49

5.6 Crown Zellerbach Regression Equations................................... 53

5.7 Characteristics of Secondary Effluents Used in Color Comparison 67

5.8 Color Monitor Measurements of Mill A Caustic Stage Bleaching Effluents.......... 67

5.9 Color Monitor Measurement of Mill A Chlorine Stage Bleaching Effluents.......... 69

5.10 Effects on pH Variations of Total Mill Effluents in Color Monitor Measurement.......... 71

5.11 Instrument *vs* True Color.. 72

6.1 Symbols Used in Model Printouts... 82

6.2 Model A Results... 82

6.3 Model B Results... 84

6.4 Model C Results... 85

6.5 Model D Results... 86

6.6 Model Results Summary... 88

6.7 Lease Squares Estimates and Approximate 95% Confidence Intervals for Parameters in Equation 5.......................... 96

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

6.8 Summary of Process Losses 96

8.1 Spill Control System Pumps 137

8.2 Minicomputer Evaluation and Costs 145

8.3 Station and Device Assignment Loss Control System 168

8.4 Messages Generated by LCS System Operation 172-173

8.5 File Number Specifications for MMPB 176

6-1/2"
9-1/8"
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SECTION 1

ABSTRACT

Because spills and losses of process materials are unavoidable consequences of production processes, and because the processes comprising the production of chemical wood pulp use large amounts of water to transport heat, chemicals and product through the processes, there is a need for a management strategy and system to control these spills and losses. In order to develop feasible strategies, it is necessary to define the problem and this was accomplished through examination and characterization of process effluents from many kraft pulp mills and investigation of existing loss control systems in the industry. In addition, dynamic computer modelling, using data obtained from monitoring process effluents, was employed to illustrate the utility of this technique to arrive at various loss control strategies for particular process configurations.

In order to justify the installation of a loss control system for other than environmental reasons, it should show a return on the investment. Examples were presented, using data obtained from the monitoring effort, of the cost offset which may accrue from recovery of chemicals and organic solids and obviating the necessity of having the losses go to wastewater treatment.

A loss control strategy was developed for the pulping, pulp washing, and chemical recovery areas of a large kraft pulp mill. The strategy was implemented and operated in the existing spill control system of the mill and control was successfully effected utilizing a digital computer. In addition to managing process losses, the direct digital control system also allowed gathering, processing and managing data obtained from the sensors

monitoring the system. Pertinent recommendations were made as a result of this research and demonstration effort.

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Section 2

SCOPE AND OBJECTIVES

INTRODUCTION

The operation of the chemical and physical processes for turning wood into paper represents a complex blending of batch and continuous processes. The variation in effluent from this series of unit processes can have an effect on process control performance and final effluent characteristics as well. Aside from those load variations caused by changes in production schedules, a category of non-continuous variations has been identified stemming from tank overflows, process instability; e.g., evaporator carryover, spillage and leakage during process transfer, and cyclic operations; e.g., process cleanups and maintenance. Because sources and frequency of such load variations must vary substantially from one mill to another, there is a need for a management strategy for dealing with such losses.

While a given process is in balance the variation in waste load, reflected in wastewater characteristics such as suspended solids, dissolved organics, pH, salts and other constituents, is sufficiently uniform to identify the load reduction potential associated with control of variation in process effluents. However, when a process is not in balance, the magnitude and duration of the variations from individual processes is not sufficiently defined to develop a management strategy which covers the sensing, collection and recycle or equalization of process losses.

A number of factors have necessitated increased management or control of process imbalances in the chemical pulping industry. These factors include the installation and operation of sophisticated wastewater treatment technology, stringent emission limitations both in air and water, rapidly increasing energy costs with consequent increases in raw material costs and the employment of production process controls of narrow tolerance. These and other factors have resulted in decreased effluent volumes and waste loads per ton of production with the result that process variations due to upsets, spills, leaks and overflows become a significant factor in the total volume and strength of current mill effluents. Process variations and abnormalities have thus gained importance from economic and environmental viewpoints and the need has become evident for loss control management strategies within a pulping and recovery complex. This need is being manifested within the industry by the installation of loss control and spill recovery systems.

SPECIFIC GOALS AND PURPOSES OF THE PROJECT

This project was designed to be conducted in two phases. The first phase had two objectives, the first of which was the characterization of process liquors and effluents in the kraft chemical pulping industry. Thus, laboratory and field studies were undertaken to define both normal process effluents and discharges representing imbalances or spill conditions. The magnitude and frequency of these spills was also examined. The second objective of this first phase was the development of computational routines and control algorithms using the analytical information being obtained in the above characterization in order to assemble the necessary process control hardware and software to effect a loss control management strategy at an operating kraft mill.

In conjunction with this first phase, existing loss control philosophies and systems were examined and evaluated both from the literature and through field reconnoissance. The characterization and spill system evaluation involved contact with approximately sixty kraft mills located in various parts of the United States, Scandinavia and the Soviet Union. In addition, various instrumentation was evaluated with the objective of determining its suitability for process effluent monitoring and detection of process spills.

The second phase of the project involved the installation of a direct digital loss control system, including the strategy developed in the first phase, at an operating kraft mill. The mill had designed and was installing a spill system employing manual and analog control in the pulping and chemical recovery process areas. The primary objective of this second phase was to demonstrate the utility of direct digital control using a process computer to effectively manage a loss control system.

The secondary objectives were a) to determine the information needs to inform process and system operators of events occurring in the loss control system, b) to summarize data for record keeping purposes and to evaluate the operation and suitability of sensors, measurement systems and control elements along with the computer hardware and software.

SECTION 3

SUMMARY OF FINDINGS

INTRODUCTION

The loss control strategy project discussed in this report is a research and demonstration effort with the goal of determining the applicability of direct digital control employing a process computer to the detection and management of process losses or spills. The project was conducted at a host mill of Brown Company in Berlin, N.H. and utilized an existing spill control system. The spill control system served a portion of the kraft chemical pulp mill including the pulping, pulp washing, and chemical recovery areas which are traditionally the areas most susceptible to process losses of significance. Other areas of the mill, such as causticizing and bleaching, were not included in the spill control system although they were included in the overall mill sewer monitoring system. Depending on an individual mill acidity/alkalinity balance, it may be beneficial to include the causticizing area in a loss control system, although it should be segregated from the pulping and recovery control system because of dissimilarities of process chemicals.

Loss Control Strategies

Pulping, chemical recovery and causticizing areas are the most logical process areas in the pulp mill to install a loss control system. The planning and installation of a spill control system and the installation and operation of secondary wastewater treatment frequently results in a decrease in the magnitude and frequency of spills. This is probably due to increased awareness on the part of operating personnel of the consequences of loss of process material as a result of an instrumented monitoring system.

It was found that many companies in the pulp and paper industry have installed some type of loss control management system to prevent the loss of economically valuable materials and to protect wastewater treatment systems. Examples of such installations were presented in Section 4, as was a review of a computer based system for monitoring process losses and wastewater discharges of the Scandinavian pulp and paper industry.

Mill Surveys and Characterization

A sampling and analytical program, described and discussed in Section 5, was conducted to characterize various kraft pulping and bleaching process streams and effluents from kraft mills throughout the country. These mills pulped different species of wood under various pulping conditions producing various end products.

Consistent relationships were found among the parameters analyzed in specific process streams. The results confirmed the value of using an easily monitored parameter, conductivity, to predict other less readily monitored parameters. The results also suggested ranges of normal and above normal parameter values for specific process streams.

Linearity of response of conductivity to increasing concentrations of parameters of interest; i.e., Na, TOC, and TDS, was found thus allowing conductivity to be a linear predictor of those parameters.

A major sampling effort was conducted at two kraft mills to characterize normal process effluents and those discharges constituting spill situations. A wide range of parameter values was found and linear correlations between conductivity and Na, TOC and TDS were made for each of the sampled stations by regression analysis. Correlation coefficients were generally greater than 0.9 and the results from similar stations at the two mills were comparable.

Flow measurements in process sewers were made utilizing various techniques to determine volumes and masses of spills. Various continuous sensors or monitors were evaluated during the course of the project and these were discussed in detail.

Conductivity--

Conventional and electrodeless conductivity sensors were found to be equally reliable with the electrodeless being better able to withstand a harsh environment particularly one containing erosive of scaling material. Conductivity instrumentation is readily available, familiar to industry operating personnel, reliable and relatively inexpensive.

Sodium--

A sodium specific ion continuous monitor was operated at two mills. The monitor system was found to be reliable and accurate. However, the system to provide a sample to the monitor, which was not a part of the sodium monitor, was unsatisfactory and frequently plugged. It was concluded that any instrumentation which needs an off stream, clean sample would encounter similar problems when monitoring a process effluent with variable characteristics. The problems encountered in sampling and sample conditioning require further work. In addition, monitoring instrumentation to detect specific constituents is relatively expensive and the cost to monitor a network of stations, as was done in this project, probably could not be justified and would preclude their use in most mills.

Color--

A continuous photometric color monitor was evaluated by comparing its output to the results of true color analysis of pulp mill effluents by the standard method. The monitor was found to accurately track color con-

concentrations of treated kraft mill effluents. Fluctuations of pH in the range 4 to 10 did not cause appreciable errors but chlorination stage effluent at pH 1.8 could not be accurately monitored. Suspended solids in concentrations up to 300 mg/l resulted in monitor color measurements no more than 14% higher than true color, but errors increased markedly at higher suspended solids concentrations.

Other Parameters--

Other parameters for a spill monitoring and management system, including pH, temperature, and organic indicators, were discussed but not evaluated in the field. In general, it was believed that their insensitivity to detection of excursions, their sampling problems or their cost would preclude their application.

Development of Loss Control Strategies--

Approaches to the development and design of loss control strategies were discussed in Section 6. These included quantification of the nature and frequency of intermittent process losses. This can be accomplished by monitoring, sampling, and analyzing individual process sewers. In conjunction with this, records of events causing the intermittent losses should be kept by the process area operators for analysis of the major process imbalances and to allow segregating dissimilar material spills for proper disposition. The maintenance of records explaining high values of monitored parameters; e.g., conductivity, often results in a decrease in frequency of spills due to increased operator awareness and attention.

Various dynamic computer modelling systems are available to simulate process conditions. These could use as input actual data from a process sewer monitoring system to simulate process conditions and provide a means to design a control strategy resulting in optimum design and sizing of pumps, pipes and spill tanks. Some examples of the use of a particular dynamic simulation modelling technique were presented to illustrate the utility of this approach in the design of loss control strategies. The use of time series analysis was also described to demonstrate its application and to show its potential for characterization and control of process losses.

Loss Control Economics--

Installation of any process in an industrial facility must either show a net economic benefit or be required simply as a part of doing business, preferably the former. Loss control strategies may produce an economic return and this was presented in Section 7 through an example of an operating system. Considered were the heat value of recovered solids, the value of recovered chemical and net cost of wastewater treatment versus the cost of evaporating extra water. With the spiralling cost of energy, the potential benefit of a loss control system warrants consideration.

The considerations noted above were also used to compute the minimum concentration of recoverable solids. This was done using correlations between conductivity and recoverable materials as developed in this project. The results showed favorable operating cost offsets for recovery of dilute streams, relative to typical process streams. The minimum concentration which was computed was approximately 1.5% solids. This agreed very closely with what was being accomplished in the example cited above and further described in the body of the report and also agreed with calculations made independently by several companies in the industry.

The economics of a spill control system will vary with individual mill situations. A major consideration concerns availability of capacity for evaporation, recovery, and stream generation.

An example was presented of the economics of alternate evaporator design to handle the increased water load. No attempt was made to deal with the economics of recovery furnace and causticizing system design and costs to process the additional solids and the effect on mill chemical balance. These obviously depend on individual mill characteristics.

Other means to increase the solids concentrations of recovered spills should be and are being investigated to reduce the load on multiple effect evaporators and possibly effect energy savings. One such process is that of freeze crystallization which has been employed in the desalting of brackish and sea waters. Increased energy costs may make this process attractive. Another alternative may be the provision of extra vapor head space or provision of demisters in the vapor heads of the evaporators to prevent carryover of liquor to the condensate.

Loss Control Strategy Application

The pulping, pulp washing, and chemical recovery systems at the Brown Co. mill complex were described as they relate to the existing spill control system. The elements of the latter system, comprising the external hardware which intercepts, stores, and recovers spills, were described in detail in Section 8.

The basic purposes of the direct digital computer control system were. 1) gather sensor data, 2) analyze this data for loss detection and data logging and 3) effect realtime control reacting to spills. These basic purposes were successfully accomplished by the hardware and software described in detail in this report. Design, specifications and selections of the computer control system were outlined as were the functions of the individual elements.

In over two years, the system has been in continuous operation either on analog or digital control. Material intercepted has always been returned to recovery, not pumped to the sewer. The spill tank has generally been less than 50% full and usually 20% full due to the philosophy of always returning material to recovery. The spill tank has also served as extra weak black liquor storage. During a representative 18 day period of operation, the system intercepted and returned 12.5 tons of sodium as Na, 15 tons of BOD and 67.5 tons of dissolved solids. During the entire period, computer availability was very close to 100% and total system availability was approximately 90%. The reasons for any downtime of system components are outlined. The external hardware or sensors are the most critical elements of the system as the strategy depends on receiving meaningful signals for conversion into data to be analyzed to make decisions. Thus sensors must be routinely checked daily and calibrated and maintained as necessary.

The one deficiency of the computer control system is one common to many process control systems. That deficiency is the lack of feedback from the controlled elements. Feedback would be highly recommended and desirable in such a system. Another recommended feature would be additional hardware for mass data storage so that long term data could be readily analyzed for purposes other than loss control. These items are discussed more fully in the report.

Linear relationships were used to determine concentrations of Na, BOD and TDS as functions of conductivity. These relationships were found to hold reasonably well. The concentrations were multiplied by the flow measurement data to obtain mass rates of losses of these constituents. The mass rates were then used in the strategy to make the decision as to whether or not an interceptible spill was occurring. Using the mass rate and a time interval for an occurrence to be out of tolerance resulted in smoother operation and less on/off control relative to an analog system. It also avoided reacting to a high concentration, low volume spill.

Recommendations concerning the loss control strategy and system components are made in Section 8.

SECTION 4

REVIEW OF PULP MILL LOSS CONTROL STRATEGIES

AREAS SENSITIVE TO CONTROL

The kraft pulping process involves the production, use and recovery of concentrated chemical solutions. The two major series of cyclical process operations are shown schematically in Figure 4.1. The major process areas; such as cooking, washing, evaporation etc., are generally independent to some degree. But, in order to keep pulp production continuous, each process must run continuously. Thus, buffers in the form of storage must be provided between the processes to allow for imbalances in supply and demand. Storage is provided in the form of retention time in the process equipment and in tanks and vessels designed for this purpose. Table 4.1 shows minimum recommended storage times or various process liquors. The level at which the various tanks are normally operated will also effect storage capacity, thus determining how long downstream processes will be able to be operated after a scheduled or unscheduled interruption of upstream processes.

Since the most concentrated liquors are handled in the pulping, recovery and causticizing areas, these areas are the most logical to subject to strategies to control and recover process spills. In spite of good operation and storage provided, imbalances and equipment failures do occur resulting in spills or losses of process chemicals and liquors. These spills also represent economic losses because the lost chemical must be replaced by purchased chemicals, and in the case of black liquor, the heating value of the

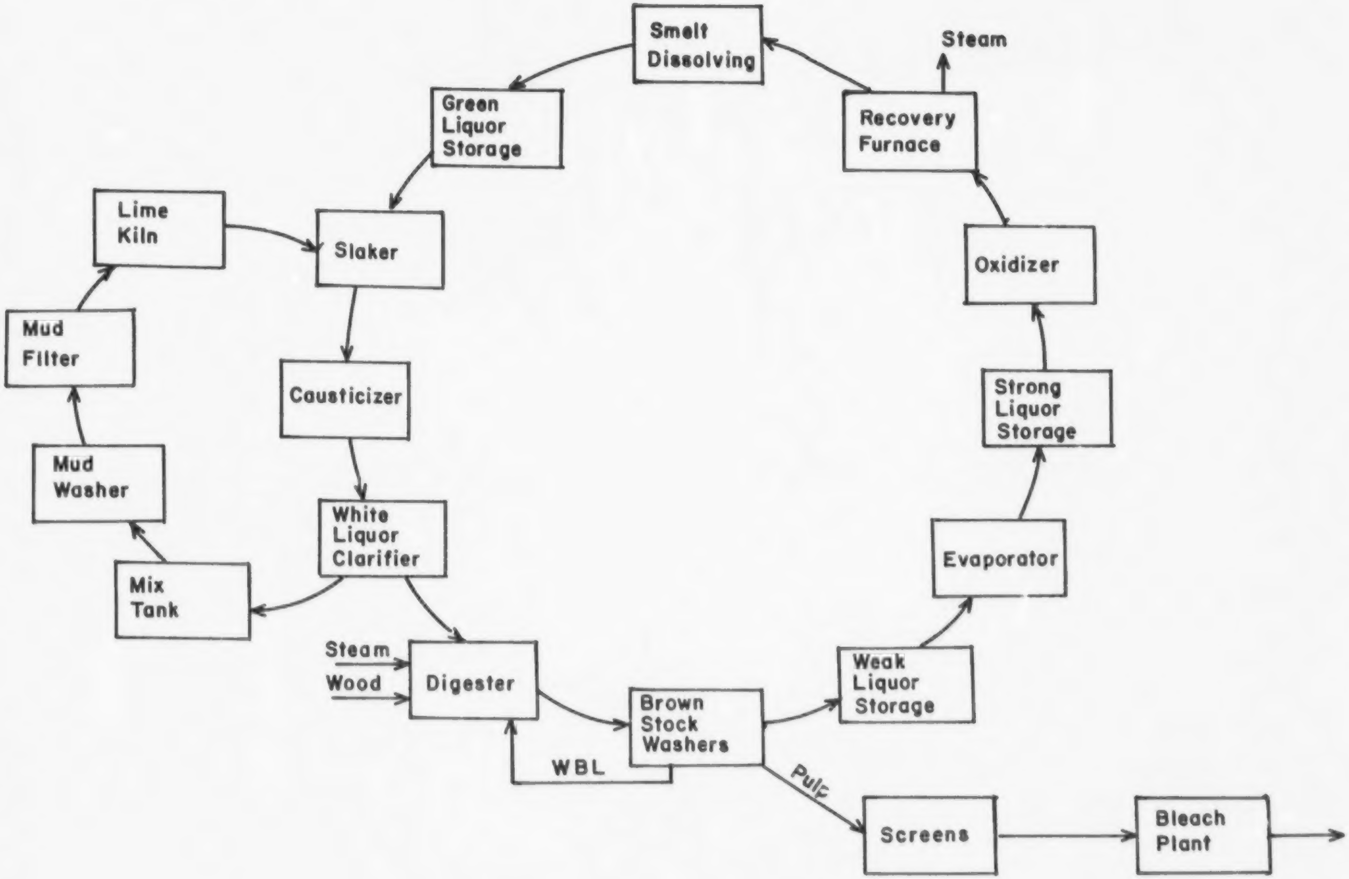

Smelt Dissolving
Steam
Green Liquor Storage
Recovery Furnace
Lime Kiln
Slaker
Oxidizer
Mud Filter
Causticizer
Strong Liquor Storage
Mud Washer
White Liquor Clarifier
Evaporator
Mix Tank
Steam
Wood
Digester
Brown Stock Washers
Weak Liquor Storage
WBL
Pulp
Screens
Bleach Plant

Figure 4.1 Kraft Pulping and Chemical Recovery Closed Cycle Process

organic solids has been lost. Also, the resulting increase in organic strength (BOD) of the mill effluent must be removed at the wastewater treatment plant. For example, losses of one percent of the weak black liquor generated in a day at a 500 tpd kraft mill would represent approximately $340 for saltcake make up, $230 for lost heating value and $190 for additional BOD removal. The increase in BOD loading to the wastewater treatment plant would be approximately 4000 lbs and may be critical for a tightly controlled mill operating close to stringent effluent limitations.

Thus, it seems apparent that areas within the pulping and recovery processes are those which would be most amenable to loss control strategies. Spills from these areas are generally of an intermittent and random nature and are difficult to quantify with respect to time of occurrence and magnitude. A planned approach to prevent, control and intercept spills from these areas frequently results in a decrease in their frequency and severity, better control of the production processes involved and more stable operation of these processes. A determination must therefore be made as to what combination of control systems will be best in a particular case.

An important part of spill control is the involvement of operating and supervisory personnel. In order for a control system to function effectively, the people responsible for its operation must be informed of its purpose, goals and mode of operation and must be instructed of these elements through meetings and operating manuals. In addition, they must be kept informed of the continuous operation of the system by the use of centralized control panels, warning and alarm lights and daily reports.

TABLE 4.1 RECOMMENDED SIZE OF LIQUOR STORAGE TANKS*

Tank	Storage Time-hr.
Weak Black Liquor	12
Strong Black Liquor	12
Green Liquor	24
Weak Wash	12
White Liquor	24
Lime Mud	12
White, Green or Weak Liquor Dump	12

*After Tappi Monograph 32, Chemical Recovery in Alkaline Pulping

EXAMPLES OF MILL PROGRAMS CURRENTLY OPERATING

Spill or loss control has been a consideration in the pulp and paper industry for some years primarily for two reasons; a) a loss of process materials represents an economic loss, and b) spills may interfere with the proper functioning of wastewater treatment facilities and cause violation of permits to discharge to receiving waters. In addition, many state regulatory agencies have required mills to have a formal action plan to prevent pollution incidents due to spills. Much of the background for spill prevention, the effects of spills and the measures taken by individual mills to control or prevent spills has been discussed in NCASI Technical Bulletin No. 276. Mention will be made here of some installations not covered in that bulletin.

A bleached kraft mill was constructed to include a separate sewer system for the collection and recycle of potential losses from high BOD process streams. The waste treatment system was designed to achieve 90% BOD removal with normal effluent loads and several contingencies were provided to protect against abnormally high BOD loadings. Among the contingency features was a strong waste collection system to capture and recycle losses.

After the need for a strong waste system had been established by receiving water and permitted effluent discharge considerations, the system was designed. A collection tank was selected over a spill pond based on potential odor problems from the containment system and potential liquor handling difficulties during extremely cold winter weather. The size of the collection tank was subject to a wide range of estimates based on past experiences of the parties involved. The final size selection was based on the logic of having a storage tank large enough to accommodate a total spill of the largest process tank served by the system. Thus, the collection tank volume was sized equivalent to the volume of one of the two weak black liquor storage tanks.

Another major point of concern during the design phase was the rate of recycle of the collected wastes into the weak liquor system. Operators were concerned about evaporator capacity and the environmental group was concerned about keeping the collection tank empty for potential spills. The compromise reached was a recycle pump capacity which amounted to about 5% of the design evaporator capacity. In terms of spill storage capacity, the recycle pump would empty a full tank in 6 days.

The installed system was designed to collect tank spillage and transfer pump leakage throughout the black liquor system beginning with the filtrate from the first stage of brown stock washing. Also included was the evaporator boilout storage tank, which was another of the loss control contingencies in the system. In addition, the system included the steam stripper feed tank because of the high BOD condensates which would be stored there.

Collected spills flow by gravity to a collection sump. Collection mains are 15 inch diameter pipes. Branch collection piping varies from 8 to 15 inches depending on the size of the tank involved. The collection sump has a capacity of 5000 gallons. Spills are transferred to storage by a 1500 gpm lift pump (60 HP). A duplicate standby pump was provided.

The spill tank has a capacity of 850,000 gallons. The tank is electrically heated by an internal heater and is insulated. The recycle pump is rated at 100 gpm (2 HP). The tank vent is equipped with an activated carbon adsorption chamber because the tank location was not convenient to the vent gas collection system used for other liquor tanks. The initial design concept was to operate the collection sump lift pump by a high/low level controller to transfer all collected effluent to storage. In routine operation, there was a steady flow of relatively clean water from pump seals and cooling uses into the sump. This dilution was considered a significant misuse of storage and evaporator capacity. The system was modified by the addition of a conductivity sensor and automatic valves so that waste having conductivity less than 2 mmho/cm is now directed to the general process sewer system rather than to storage. This change is the only major modification since startup.

During the first few months of mill operations, the spill system was severely tested. The average level in the storage tank was about 50% of capacity with the recycle pump running almost continuously. There was one significant spill during this mill shakedown period due to insufficient storage. This was the only event when storage volume proved inadequate. After this initial startup phase, the system went through a period of about two years when normal operation would find the tank at about 25% of capacity with the recycle pump running about one day per week. More recent experience is that the tank is normally nearly empty and the need for recycle is rare, perhaps averaging one day per month.

In addition to the planned spill collection service, the strong waste storage has been employed on several occasions to provide extra liquor storage capacity. Mill operators have been able to avoid kraft mill shutdowns by storing liquor during problems such as recovery boiler tube failures. This type of use alone has probably justified the cost of the strong waste system. Other than the initital few months of operation, the size of the storage has proved more than adequate. Following startup, a storage capacity of about 50% of the installed tank would have been sufficient for the spills encountered. However, it is noted that protection for complete loss of a weak liquor storage tank would not be provided by a smaller storage.

The only real problem with the spill detection and collection system and one which may be of concern at any kraft mill occurred when a spill of soap from the weak liquor tanks was not detected by the conductivity monitor. The soap was consequently pumped to waste treatment where it interfered with the process instead of being diverted to the spill tank. Since the weak liquor tanks have level control and alarms, when high level is alarmed, the evaporator operator now observes the sump and manually switches the valves so that a soap spill is pumped to the spill collection tank.

In four years of mill operation, there was never a BOD discharge violation resulting from a spill situation. The spill system has been [illegible] major factor in establishing this record.

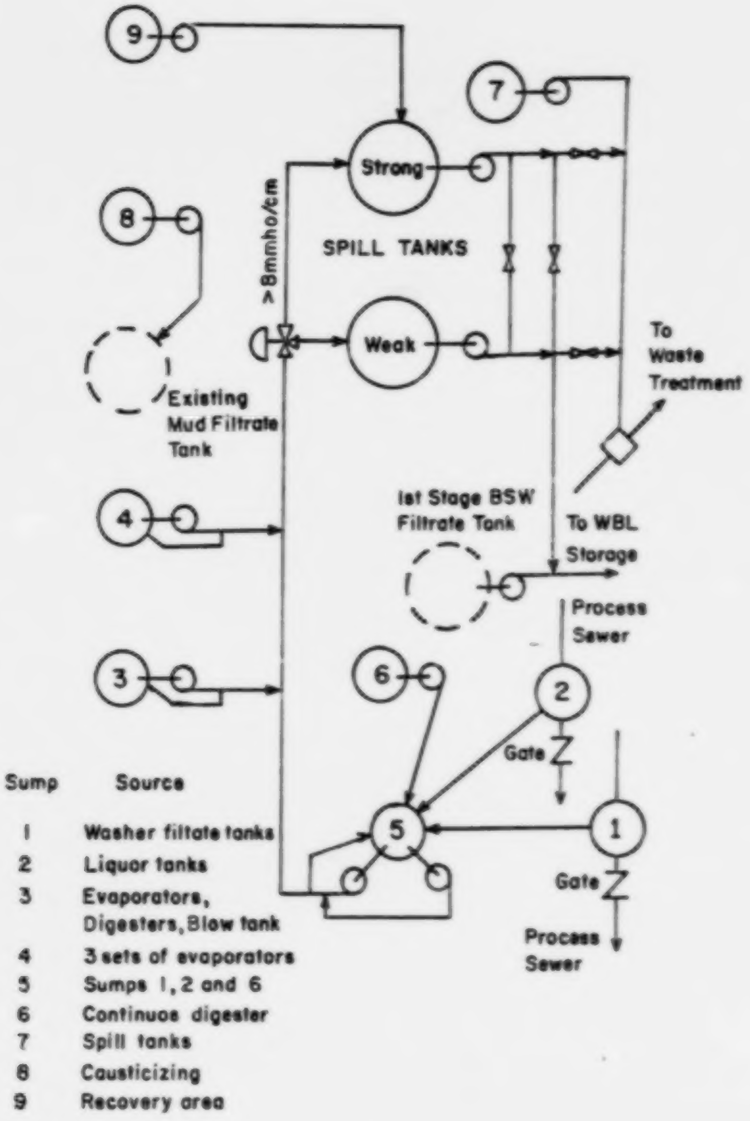
The next example involves an older 1000 tpd kraft mill. An in-mill spill control system was chosen to permit BOD smoothing rather than increasing the size of the surge basin at the Unox wastewater treatment plant or investing in more oxygen injection capacity.

The spill system presently consists of nine sumps, two 700,000 gallon spill tanks and associated sensors, pumps, valves and piping. The purposes of the system are (1) to reclaim lost chemicals, and (2) to protect the Unox activated sludge treatment plant. In addition to the spill system, there is a 1.7 million gallon rectangular surge basin adjacent to the Unox aeration basins. This basin is also used as a standby primary clarifier and is equipped with outlet launders.

A schematic of the system is shown in Figure 4.2. Spill collection sumps are constructed so that normal flow goes to the process sewers. On reaching a conductivity set point, valves and/or gates close, the sump fills and either causes overflow to another sump or level switches activate sump pumps as well as throttling valves to prevent the pump from running dry. The spill is then pumped to the two spill tanks via a single header. When the spill arrives at the spill tanks, a conductivity probe routes it to either the rich or lean spill storage tanks based on a set point of 8.0 mmhos/cm. Strong spills are flow metered back into weak liquor storage and weak spills are metered to the sewer from the spill tanks. The spill tank area is diked and has its own sump.

The major limitation of the spill control system is an inability to store and recover the large volumes the sump pumps are capable of delivering due mainly to dilution by relatively clean waters such as cooling and seal waters. This problem has presently been addressed by separately collecting clean waters, thus diverting them from the sumps.

All sumps are equipped with conductivity probes, meters, recorders and alarms, the latter two located at an operator panel. The conductivity probes are generally off-line with a water aspiration sampling system. The probes are checked daily by instrument personnel and calibrated every few days.


9
7
Strong
SPILL TANKS
8
>8mmho/cm
Weak
To
Waste
Treatment
Existing
Mud Filtrate
Tank
4
1st Stage BSW
Filtrate Tank
To WBL
Storage
Process
Sewer
3
6
2
Gate
5
1
Gate
Process
Sewer

Sump	Source
1	Washer filtate tanks
2	Liquor tanks
3	Evaporators, Digesters, Blow tank
4	3 sets of evaporators
5	Sumps 1, 2 and 6
6	Continuos digester
7	Spill tanks
8	Causticizing
9	Recovery area

Figure 4.2 Schematic of Spill Control and Recovery System at a 1000 tpd Kraft Mill

The major sources of spills include smelt dissolving tank overflows; washing out of lines; pump and agitator packing leaks; shutdown and draining of equipment; evaporator boilouts and startups; carryover of liquor in the evaporators to the condensate, and human error.

The frequency of spills is almost continuous for weak spills from some areas; e.g., evaporators. It was estimated that spills occurred 2 hrs/day per sump with two or three major incidents per day. Black liquor leaks are the most severe because of increased oxygen demand, foaming, etc.

The surge basin volume was selected based on raw waste and treatment pilot plant data. Retention time was selected which would account for the duration of most peak flows. The surge basin would be used to scalp these peak flows to allow the BOD load to the waste treatment plant to return to normal.

The spill tank size was selected as twice the weak black liquor storage volume. Two spill tanks were constructed to segregate strong spills for reclaim and weak spills for treatment. Level in the two tanks is displayed and recorded in the liquor preparation operator area.

The concentration dividing line between weak and strong spills is set at 8 mmhos/cm and the separation is made at the spill tanks by automatic valve operation based on this set point, which was arrived at by experience. The set point can be changed if it becomes desirable to recover leaner material.

Spills in the causticizing area do not go to the spill tanks. Mud is pumped to the lime mud washer. Spills are pumped to the mud centrate clarifier. However, clarifier operation is frequently upset because of the high volume passing through this sump and the discharge of the sump pump. Plans are underway to remove the clear waters from this sump.

Parameters monitored in the system include conductivity, return flow from the spill tanks, level in the sumps to throttle pump discharge and spill tank levels. Conductivity is also checked manually at the sumps and spill tanks. In addition, flows, pH, oxygen consumption and torque on the mixers are monitored at the secondary treatment plant and give indications of spills reaching that point.

This particular loss control system is extensive and sophisticated. The design and operation of the system makes it a prime candidate for computerized control. In addition, continual modifications are being made to improve the operation of the system.

The next example cited is an unbleached kraft linerboard mill which depends on extensive process and loss control to meet effluent limitations. The only external wastewater treatment is clarification; thus organic losses must be kept to a minimum and this has been accomplished through extensive water reuse, condensate distillation, spill control and provision of adequate storage for process liquors. Implementation of these measures has resulted in a 75% wastewater volume reduction and an 88% reduction in effluent BOD.

A large part of this program involves the disposition of condensates. Clean condensates are reused directly and dirty condensates are distilled to remove volatile organics and then reused in causticizing and brown stock washing. All condensate streams are monitored using conductivity probes and are automatically diverted to the weak black liquor system if they become contaminated; i.e., the conductivity exceeds a predetermined set point.

All process liquor storage tanks are equipped with level monitors and alarmed at high level. In addition, options were provided in the piping for

4.12

transfer and storage of liquors. In the recausticizing area, pumps are controlled by level probes to transfer excess liquors to the mud washer and mud storage capacity was doubled.

Spills occurring in the pulping and pulp washing areas are routed to one of two spill tanks and are then pumped to the digester blow tank or to the liquor recovery system on level control.

Conductivity probes in the system are checked daily by instrument personnel and a daily inspection of and report on the system is conducted by the technical department. The inspections serve to locate obvious sources of spills and to keep operating personnel informed of the operation of the system.

Another example is a 1000 tpd unbleached kraft mill, which installed a spill containment system for the primary purpose of preventing surge or shock loads from being discharged to a publicly owned treatment works. The system consists of four main elements: (1) containment structures to capture spills, (2) pumps and piping to return spills to the process, (3) instrumentation for monitoring the system and for notifying operators in the event of a spill and, (4) a diversion structure and retention pond to capture, hold and discharge nonrecoverable spills at a controlled rate to the sewer. A schematic of the system is shown in Figure 4.3.

A new one million gallon weak black liquor storage tank was constructed. An existing two million gallon tank was converted to use as a spill tank for the evaporator area. An existing black liquor tank was converted to green liquor storage. A diversion structure was constructed to intercept high strength flows from the recovery area and send them to an existing retention pond and the pumps were installed to return flows from the retention pond

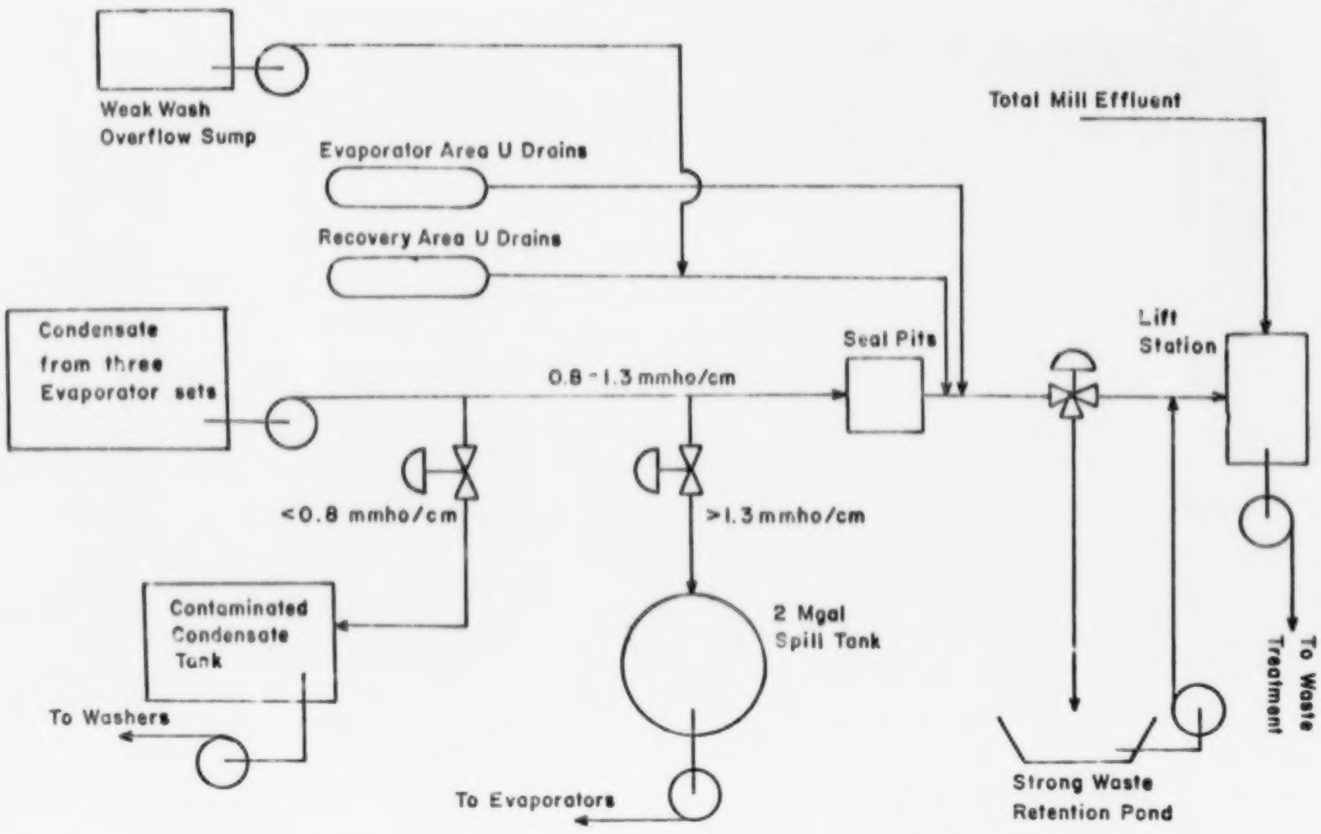

Weak Wash
Overflow Sump
Evaporator Area U Drains
Recovery Area U Drains
Condensate from three Evaporator sets
0.8 - 1.3 mmho/cm
Seal Pits
Lift Station
Total Mill Effluent
<0.8 mmho/cm
>1.3 mmho/cm
Contaminated Condensate Tank
To Washers
2 Mgal Spill Tank
To Evaporators
Strong Waste Retention Pond
To Waste Treatment

Figure 4.3 Schematic of Spill Control System at an Unbleached Kraft Mill

to the main sewer at a controlled rate.

In the evaporator area, the condensate pumps were equipped with control valves operated by conductivity probes. Clean condensate (<0.8 mmho/cm) is sent to the combined condensate tank for reuse in the final stage of brown stock washing. Moderately contaminated (0.8-1.3 mmho/cm) condensate is sent to the diversion structure via the seal pit and heavily contaminated (>1.3 mmho/cm) condensate is diverted to the two million gallon storage tank for eventual evaporation.

The diversion structure receives four main flows; three from evaporator seal pits and area U-drains and one from recovery area U-drains and weak wash sump. The diversion structure has conductivity controlled slide gates which cause diversion of flows in these sewers to the retention pond when the conductivity exceeds 7 mmho/cm. The flow otherwise goes to the lift station for pumping to the treatment plant. The retention pond return is on conductivity control to attempt to maintain a constant strength waste being sent to the treatment plant. The pond is also on level control and alarm interlocked with flows to the diversion structure to prevent the pond from overflowing.

The recovery area sump is monitored for level and alarmed at high level. The operator is then responsible for pumping the sump to green liquor storage and investigating the source of spills. As noted, the U-drain in this area is monitored and flows to the diversion structure.

The causticizing area is on a pad and drainage flows to a sump which has pumps on level control to deliver wastes to the diversion structure. The pad itself can be used for liquid waste storage in an emergency by inserting stop logs in front of the sump.

In addition to increased liquor storage capacity in the washer area, the

U-drain is equipped with a conductivity probe which alarms at the operator's panel. The operator is then responsible for investigating any spills. The tanks are equipped with high level alarms to alert the operator to possible or potential overflows. The installed cost of this spill control system was approximately $1.7 million.

The above descriptions of spill control strategies in the U.S. chemical pulping industry are representative of the types of systems operating, being installed or planned. Many more examples can be found in the technical literature. Virtually no new mill constructed in the recent past is without a planned loss control strategy, and many older mills have installed such systems or have plans to do so.

The design philosophy and degree of sophistication of these systems varies considerably depending, among other things, on the wastewater treatment facilities available, the degree of water reuse attainable and the type of mill under consideration. For example, mills producing unbleached pulp have the opportunity to attain a high degree of water reuse by recycling water from the paper machine back through the entire pulping and recovery process; such is not the case, in general, for mills producing bleached kraft pulp.

In any case, it is recognized by the industry that spills, overflows, dumps, washups and boilouts are going to occur, and that many of these contain valuable chemicals or fiber which can be profitably recovered, thus preventing losses of these materials and upsets at the wastewater treatment plant.

The Scandinavian pulp research and environmental agencies are developing process control strategies under the auspices of Nordmiljo 80. Eriksson's (1) most recent report, which is available from NCASI, contains the major developments since the project began in 1975. Nordmiljo 80 differs from the NCASI project in three major respects.

First, Nordmiljo 80 considers both dissolved and suspended organic material. Thus, a major effort is directed toward monitoring the optical properties of various waste streams for correlation with suspended solids. Second, this control strategy relies on process models to set control limits. This concept is grounded in avoiding overreaction to planned production process changes. Third, the Nordmiljo 80 project is a data gathering effort and does not exert control directly but rather relies on notifying operators of upsets so that they will take manual action.

In contrast, NCASI has concentrated on dissolved organics; i.e., liquor losses. Also, we rely on recovery economics, process capacity and environmental impact for control limits. Prescribed delays are simply built into the control software to avoid overreaction to transient surges. The NCASI strategy, for the most part, involves direct control by the computer software and hardware when a loss is detected, rather than notification and operator action.

Although the projects have different approaches, several facets are similar: (1) both systems rely on direct digital control, (2) the Nordmiljo's sample mill is also a bleached kraft mill, (3) the in-mill sensor selected for dissolved organic material is based on conductivity coupled with flow. The Scandinavian project is scheduled to be completed in 1980.

REFERENCES

1. Eriksson, L., "Measurement System for Monitoring Wastewater Discharge," Int. Assoc. Wat. Pol. Res., Ninth Int. Conf., Stockholm, June 16-17,1978

SECTION 5

MILL SURVEYS AND ANALYSIS

CHARACTERISTICS OF PROCESS STREAMS AND EFFLUENTS

An initial sampling and analytical program was carried out to characterize contents of kraft pulping and bleaching process liquors and effluents. Kraft mills in all sections of the country were invited to participate in this effort and 16 of them responded and sent samples to NCASI at Tufts University. Mill personnel collected samples, measuring temperature of the process liquid at the time of sampling, and shipped the samples along with pertinent descriptive information. The numbers of samples received from each mill ranged from 12 to 46 and represented all aspects of pulping, recovery and bleaching as shown in Table 5.1.

Samples were analyzed for the following parameters:

Temperature - recorded at the mill as the sample existed in the system
pH - conventional glass/calomel reference electrodes
*Na - sodium was measured by atomic absorption (AA) spectrophotometry and by specific ion electrode
Conductivity - conventional laboratory model platinum electrode and wheatstone bridge null meter
*Li - lithium was measured by AA spectrophotometry
*Color - NCASI method (Technical Bulletin No. 253)
TDS - total dissolved solids were gravimetrically measured by evaporation on a water bath and oven drying sample filtrate

5.2

TSS - total suspended solids were gravimetrically measured by standard methods (NCASI Technical Bulletin No. 230)

BOD_5 - BOD was measured by standard methods (Technical Bulletin No. 230)

TOC/VOC - total and volatile organic carbon were measured utilizing a Dohrmann Envirotech DC-50 analyzer

* The techniques used in these analyses were standard procedures and are available from the authors.

TABLE 5.1 SAMPLE SOURCES

Total Pulp Mill
Pulping and Recovery Areas
Brown Stock Washer Filtrates
Black Liquors
Evaporator Condensates
Liquors from Recovery and Causticizing Cycles
Filtrates from Bleach Plant Pulp Washing Stages
Miscellaneous Sewers and Drains

Lithium was measured in order to determine background concentrations since it was planned to use lithium as a tracer for flow measurement in process sewers in the field portion of the analytical program. These results indicated that lithium would be an appropriate tracer because background levels were very low.

The analytical results varied widely among the various samples but for a particular type of sample, e.g., weak black liquors (WBL), the variation in absolute value of the parameters was rather narrow. The latter precluded the development of useful predictive correlation equations because the values were closely grouped; i.e., the range of values was small. An example of a correlation is presented in Figure 5.1 for the relationship between BOD_5 and TOC of 27 weak black liquors. Although the correlation appears satisfactory, it is somewhat anomalous because of the positive intercept obtained; however, the majority of the data includes TOC's greater than 40 gm/l.

It should be borne in mind that, although these samples represented the same types of processes; i.e. kraft pulping, they were collected from mills in various parts of the country. These mills were pulping different species of woods under various pulping conditions and producing different end products.

Ratios of the various parameters were used to determine whether general relationships existed for particular sample types. Table 5.2 presents these ratios for weak black liquors having total dissolved solids concentrations less than 200 gm/l. These ratios were developed from a wide range of values of the various parameters and show, for example, that BOD_5 is approximately 25% of total dissolved solids and approximately 60% of TOC for weak black liquors.

The ratios developed and the ranges of parameter values obtained from the analyses allowed estimates to be made of set points in the loss control strategy programming and were instructive in determination of normal ranges of parameters to be encountered in the field portion of the program. In addition, the large number of analyses performed resulted in more efficient analytical procedures for the field portion of the survey.

Linearity of response of particular analytical procedures was checked by dilution of highly concentrated samples with normal process effluents. The response was theoretically expected to be of an exponential nature with

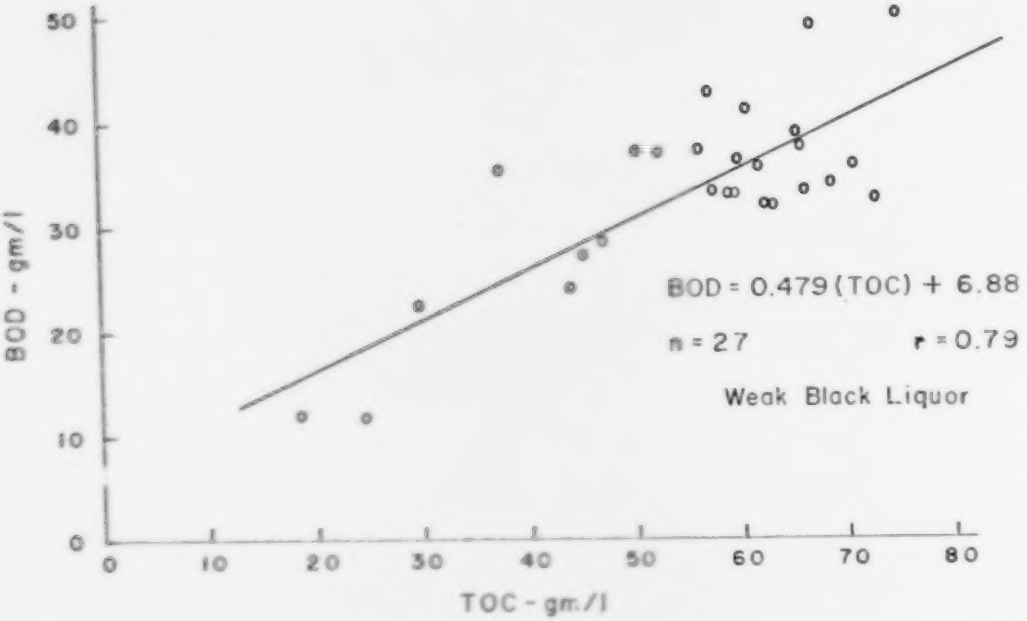


Figure 5.1 BOD_5 vs TOC for Weak Black Liquor Samples

a limiting response equal to that of the stronger sample. This assumes no chemical reactions took place and no inhibitory effects occurred. However, the response in the range of interest would be expected to be approximately linear because of the great difference in concentrations of the two liquids being blended. This is shown in Figure 5.2 and 5.3 for TOC. In Figure 5.2 the results of addition of weak black liquor (13% solids) to the normal mill effluent is shown. Figure 5.3 shows the results of addition of pulp washer filtrate (0.3% solids) to mill effluent. Both Figures 5.2 and 5.3 indicate linearity of response in the range of interest; i.e., the beginning of a spill in which above normal concentrations would occur.

TABLE 5.2 WEAK BLACK LIQUORS

(TDS<20%)

Ratio	$\bar{x}$	σ	cvar-%	NOB
TOC/TS	0.39	0.026	6.67	28
BOD/TOC	0.59	0.082	14.0	22
BCD/TS	0.23	0.038	16.2	21
Na/Cond	0.71	0.34	48.2	24
PCU-Cond	4.84	1.92	39.7	34
PCU/TS	1.58	0.53	33.6	32
TS/Cond	2.90	0.84	28.9	30

$\bar{x}$ - average, σ- standard deviation, cvar - coefficient variation, NOB - number of observations

Similarly, conductivity response is shown in Figure 5.4 as a result of adding a concentrated sample volumetrically to a normal process effluent. In this case, lime mud weak wash was added to a mill effluent sample with an initial conductivity of 0.92 mmhos/cm and conductivity was recorded as a function of the percent by volume of weak wash in the total mixture. A

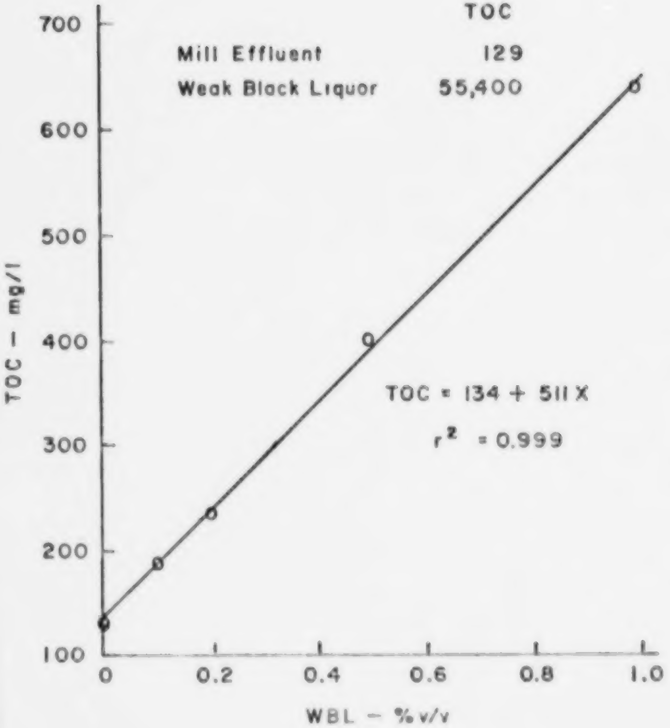


Figure 5.2 Linearity of TOC Response
Weak Black Liquor Added to Mill Effluent

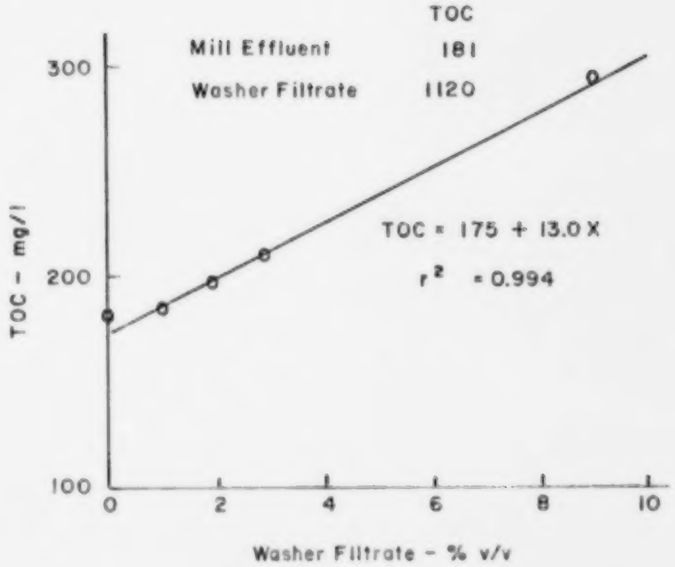


Figure 5.3 Linearity of TOC Response
Washer Filtrate Added to Mill Effluent

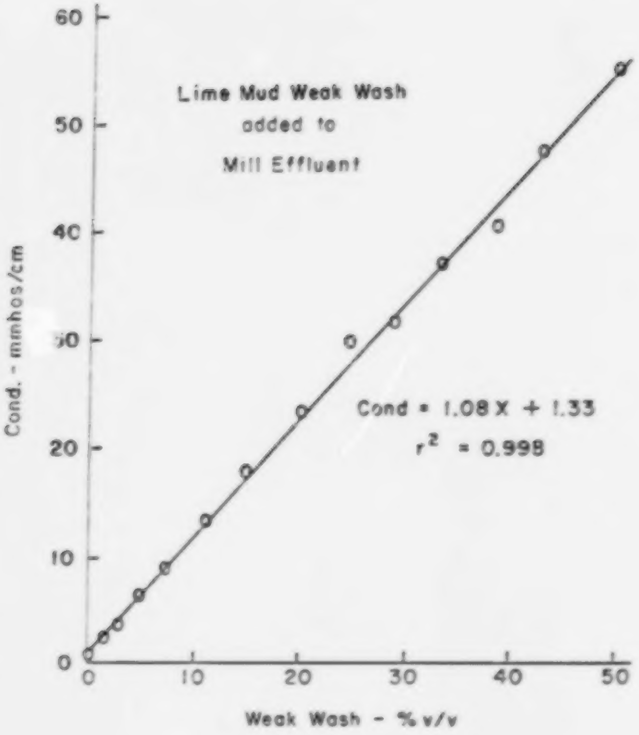


Figure 5.4 Linearity of Conductivity Response
Lime Mud Weak Wash Added to Mill Effluent

linear relationship with a high degree of correlation resulted in this case and in various other admixtures as well. Numerous other experiments suggested using conductivity as a *linear* predictor of the other parameters of interest; e.g., sodium, TOC, etc., in the field portion of the analytical program and in the development of a loss control strategy. An easily monitored parameter such as conductivity can then be used in a linear regression analysis to account for losses of process materials.

An example of typical results of analyses of process liquids from one of the mills is shown in Table 5.3.

ON-SITE MILL SURVEYS

General

Two kraft mills were visited by a survey team to conduct an intensive sampling and analysis program. A brief description of each of the mills follows.

Brown Company --

Brown Company is located in Berlin, New Hampshire, on the Androscoggin River. The mill was originally built in the late 1800's as a groundwood mill and was soon thereafter producing chemical pulp by the sulfite process. A kraft mill and a NSSC mill were built in the 1960's and the mill presently produces about 1000 tpd of pulp by the kraft and NSSC processes utilizing northern hardwoods and softwoods as furnish. The mill is fully integrated producing a variety of paper products and sends pulp by pipeline to a company paper mill located approximately two miles downstream. In addition, the mill produces market hardboard bleached kraft pulp. Kraft pulp is produced

TABLE 5.3 ILLUSTRATIVE ANALYTICAL RESULTS

Sample	T (^{o}F)	pH	Cond (mmhos)	TS (gm/l)	TVS (gm/l)	Na (gm/l)	Color (KPCU)	TOC (gm/l)	VOC (gm/l)	BOD (gm/l)
Primary Influent	61	9.0	0.690	1.12	0.63	0.250	1.55	0.317	*	-
Caustic Sewer	118	8.7	4.30	4.76	1.78	1.50	4.10	0.85	*	-
Acid Sewer	90	1.7	9.60	2.035	0.89	0.450	2.08	0.546	0.108	-
Recovery Sewer	90	10.3	0.21	0.17	0.07	0.0[illegible]0	0.081	0.015	*	-
Decker Filtrate	70	10.5	0.86	1.255	0.595	0.250	1.80	0.452	*	0.390
BSW Filtrate-Weak	125	12.2	12.20	19.54	6.81	4.00	-	7.97	*	6.00
-Intrmdt	150	12.7	31.00	61.2	20.9	15.00	105.0	12.93	*	19.00
-Strong	160	12.9	54.00	156.3	62.8	36.00	215.0	-	-	-
Weak Black Liquor	165	13.0	62.00	202.3	72.7	39.00	310.0	37.5	*	35.5
BLO Tank	132	12.9	54.00	158.8	77.4	42.00	230.0	58.7	*	-
Combined Condensate	140	11.4	2.30	3.26	1.00	0.750	5.50	1.31	0.134	1.10
Hot Well Overflow	112	10.5	0.30	0.355	0.180	0.083	0.520	0.148	0.024	0.103
White Liquor	173	13.7	260.0	200.6	-	93.1	1.90	-	-	-
Green Liquor	136	13.6	148.0	205.2	-	93.6	1.45	-	-	-
Lime Mud Weak Wash	102	13.4	98.0	72.5	-	19.0	0.280	-	-	-

* VOC is less than 10% of TOC

in nine batch digesters, washed on three sets of washers and the extracted liquor is processed through two sets of evaporators and two recovery boilers. Pulp mill and bleach plant effluents are presently treated by the activated sludge process. Pulping, recovery and causticizing effluents were sampled during the period July 12 to August 27, 1976.

Crown Zellerbach --

Crown Zellerbach Corporation owns a mill in St Francisville, Louisiana, on the Mississippi River. The mill was originally built in the early 1950's to produce coated papers from groundwood pulp and was expanded to include kraft pulping of southern pines in the 1960's. Approximately 550 tpd of kraft pulp is produced in a continuous digester, washed and bleached. Extracted liquor from pulping is processed through one set of evaporators and a recovery boiler. Total pulp and paper mill effluents are clarified and treated in an aerated stabilization basin. Selected process sewers, including pulping, recovery, causticizing and bleaching were sampled from September 23 to October 21, 1976.

Procedures

Generally the same procedures were followed at each mill. Automatic samplers, of the type shown in Figure 5.5, were installed in process sewers. The samplers were activated by timers to take a grab sample at intervals ranging from five minutes up to five hours, but were generally operated at intervals of ten minutes to ninety minutes. The samples taken were discreet samples and were collected in individual containers located on a carousel which was rotated by the sample timer. The carousel had a capacity of 12 containers but any number of samples could be taken by removing full containers and adding new ones during the sampling period. Containers were

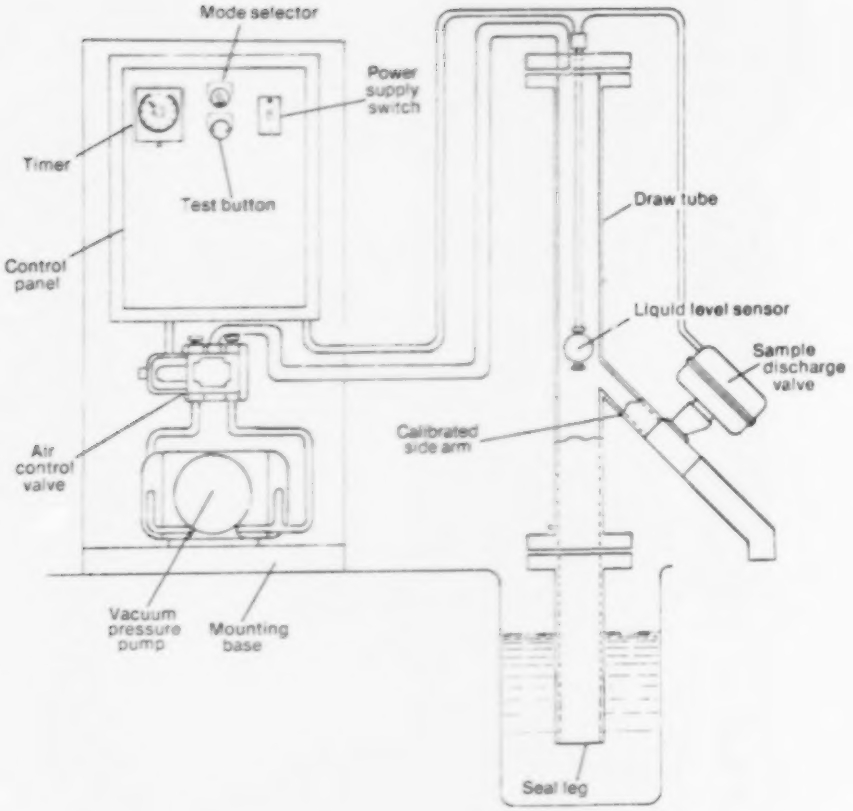

Mode selector
Power supply switch
Timer
Test button
Draw tube
Control panel
Liquid level sensor
Sample discharge valve
Calibrated side arm
Air control valve
Vacuum pressure pump
Mounting base
Seal leg

Figure 5.5 Automatic Sampler

marked in sequence and the times of sample collection were noted.

Samples were taken to a central laboratory provided by the mill and were analyzed for pH, conductivity, sodium, total dissolved solids and TOC/VOC by the procedures outlined previously, except that sodium was measured by specific ion electrode only. The number of samples analyzed per day ranged between 50 and 100 depending on the number of sites sampled, the sampling interval and the duration of sampling.

The sampling locations at Brown Co. are shown schematically in Figure 5.6. These locations were designated as follows:

Sta 1 - Digester sewer
Sta 2 - Brown stock washer sewer
Sta 3 - No. 8 recovery area
Sta 4 - Main kraft sewer at lift station
Sta 5 - No. 11 recovery area
Sta 6 - Causticizing area
Sta 7 - Total caustic at lift station

The sampling locations at Crown Zellerbach are shown schematically in Figure 5.7 and were designated as follows:

Sta 1 - Process sewer; pulping, recovery and caustic extract effluents
Sta 2 - Storm sewer; miscellaneous drains from the pulping area
Sta 3 - Causticizing area
Sta 4 - Recovery, evaporator and liquor storage areas
Sta 5 - Caustic extract and brown stock washer area
Sta 6 - Digester area

Flow Measurement

In order to know the mass of material discharged from the various processes during normal and abnormal operating conditions, the flow rate had to

TYPING GUIDE SHEET

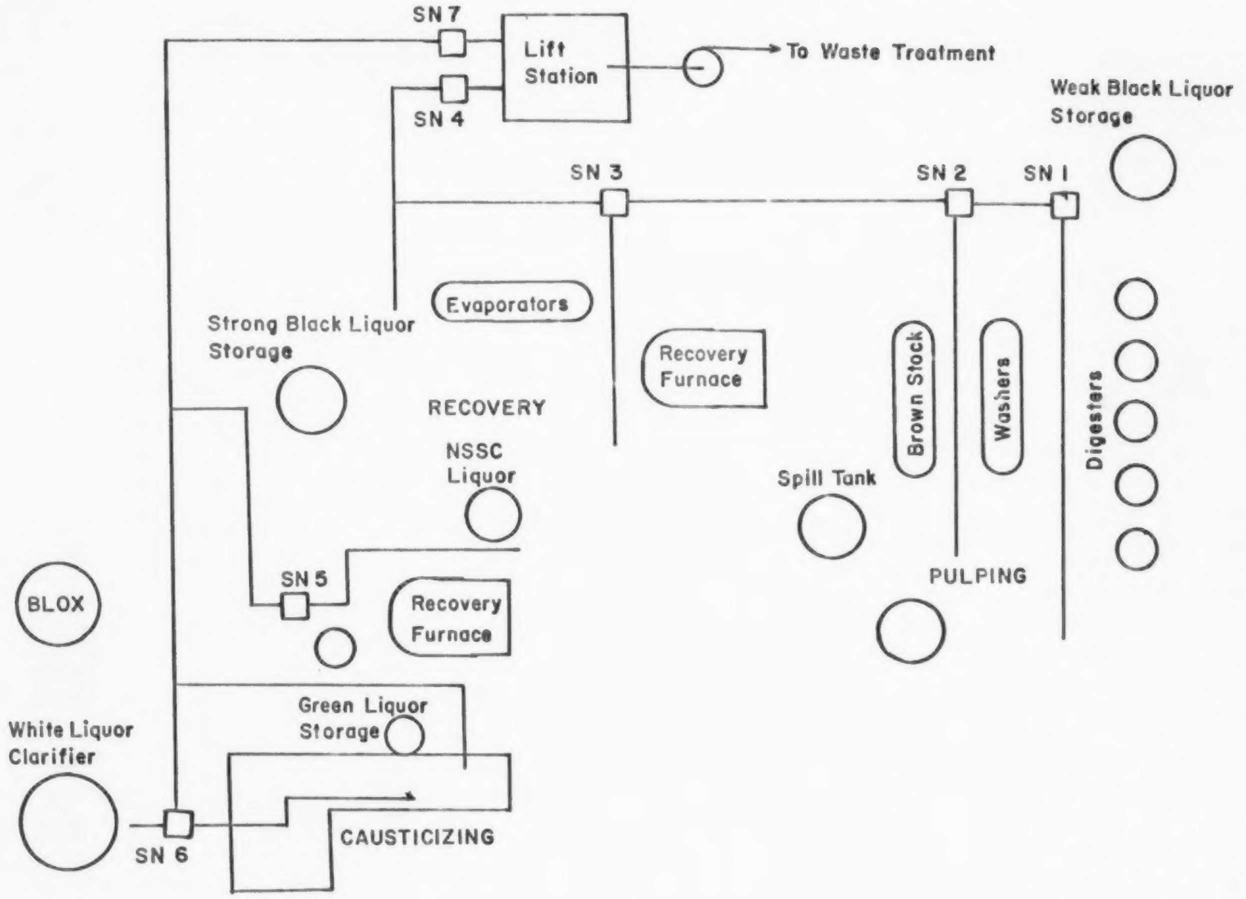

SN 7
SN 4
Lift Station
To Waste Treatment
Weak Black Liquor Storage
SN 3
SN 2
SN 1
Evaporators
Strong Black Liquor Storage
Recovery Furnace
Brown Stock
Washers
Digesters
RECOVERY
NSSC Liquor
Spill Tank
PULPING
SN 5
BLOX
Recovery Furnace
Green Liquor Storage
White Liquor Clarifier
SN 6
CAUSTICIZING

Figure 5.6 Sampling Location Schematic - Brown Company

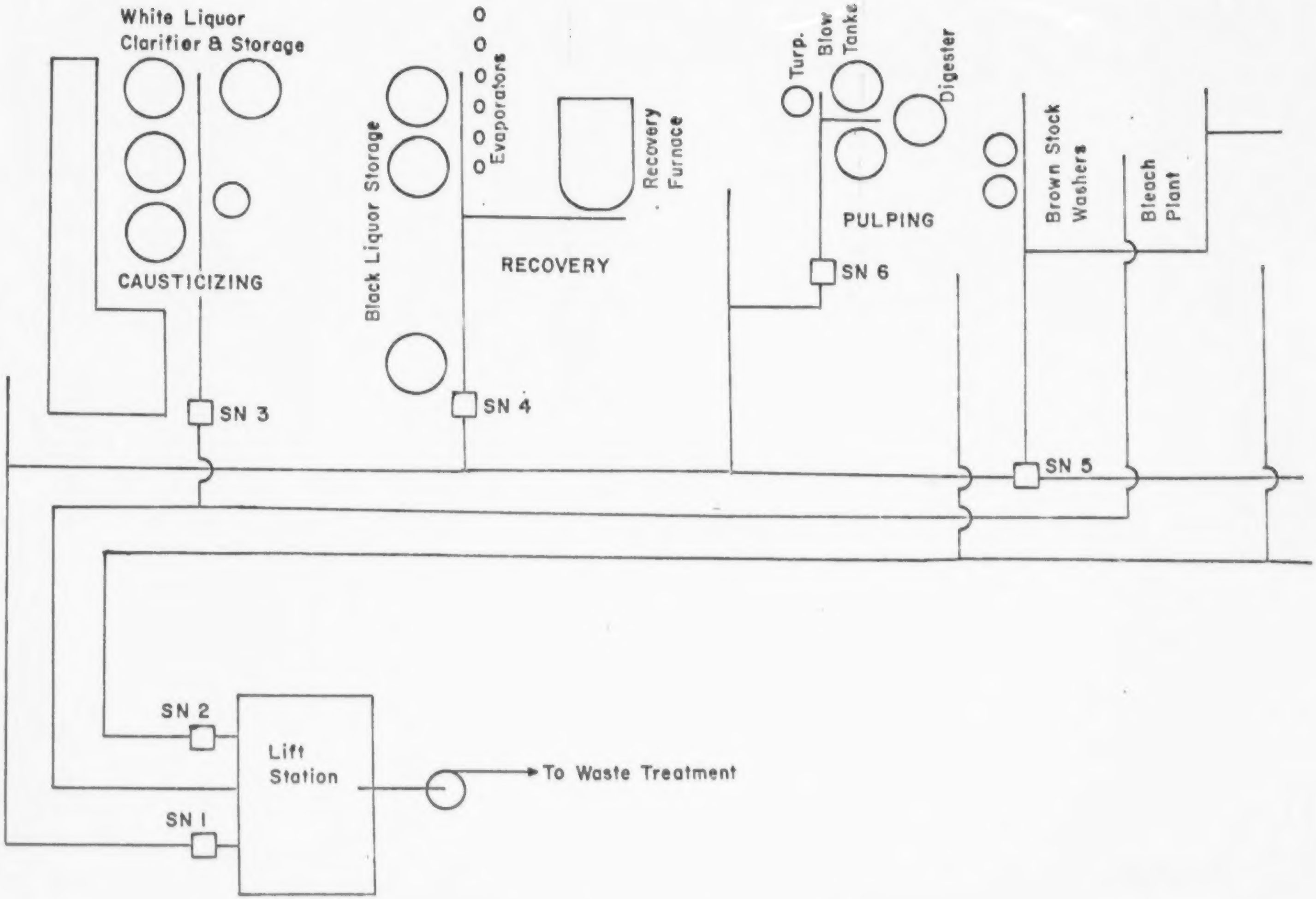

White Liquor
Clarifier & Storage
CAUSTICIZING
SN 3
Black Liquor Storage
Evaporators
RECOVERY
Recovery
Furnace
SN 4
Turp.
Blow
Tanke
Digester
PULPING
SN 6
Brown Stock
Washers
Bleach
Plant
SN 5
SN 2
SN 1
Lift
Station
To Waste Treatment

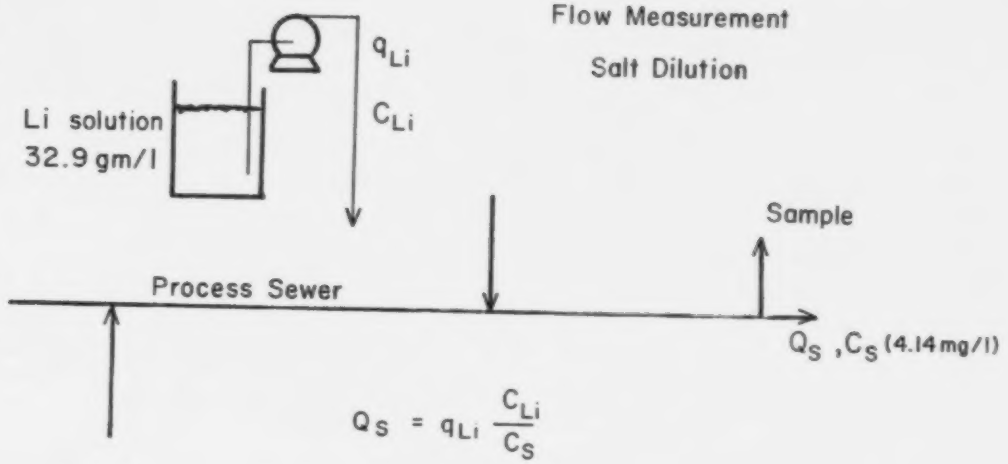
Figure 5.7 Sampling Location Schematic - Crown Zellerbach Company

be determined. When flow measuring devices existed; e.g., at large process sewers, data was obtained from mill records or by physically measuring the head behind the weir or flume. However, provision for flow measurement is not generally made in process tributary sewers; thus it was necessary to estimate flows by some other means and the salt dilution technique utilizing lithium as the tracer material was chosen for this purpose. Lithium was chosen because it is a relatively rare element. The initial analyses characterizing process liquors from the 16 kraft mills showed background levels of less than 5 mg/l at all sites and less than 1 mg/l in most samples. The procedure used is shown schematically in Figure 5.8. A small chemical feed pump was used to pump a concentrated solution of LiCl from a supply tank into the sewer at a constant rate. Samples were taken automatically at a point sufficiently downstream to ensure mixing of the LiCl and the process stream and portions of the samples were then sent to Tufts University for analysis by NCASI personnel using AA spectrophotometry to determine dilution factors. Flows were computed by the simple relationship shown in Figure 5.8. The remainder of the sample was analyzed for the aforementioned characteristics.

Flow data for the process sewers monitored is summarized in Table 5.4 for both mills. Shown are the average flows, the standard deviations and numbers of observations for the data presented.

Parameter Correlations

At the two field locations a wide range of parameter values was encountered. The ranges for four parameters (conductivity, sodium (Na), TOC and total dissolved solids) at each station and each location are shown in Figures 5.9 and 5.10. Graphically shown are the maximum, minimum and median values on a logarithmic scale. For example, from Figure 5.9, the logarithm


Flow Measurement
Salt Dilution
q_{Li}
C_{Li}
Li solution
32.9 gm/l
Sample
Process Sewer
Q_S , C_S (4.14 mg/l)

$$Q_S = q_{Li} \frac{C_{Li}}{C_S}$$

$$Q_S = \frac{73.4 \text{ ml/min}}{3785 \text{ ml/gal}} \times \frac{32,900 \text{ mg/l}}{4.14 \text{ mg/l}} = 154 \text{ gpm}$$

Figure 5.8 Salt Dilution Techniques for Flow Measurement

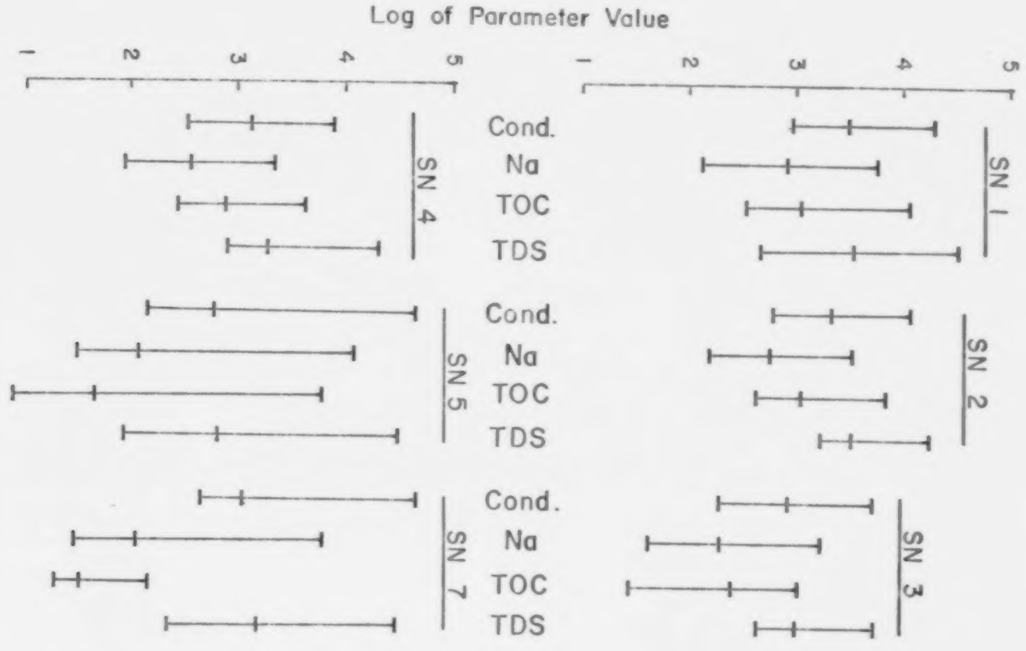


Figure 5.9 Range of Parameter Values - Brown Company

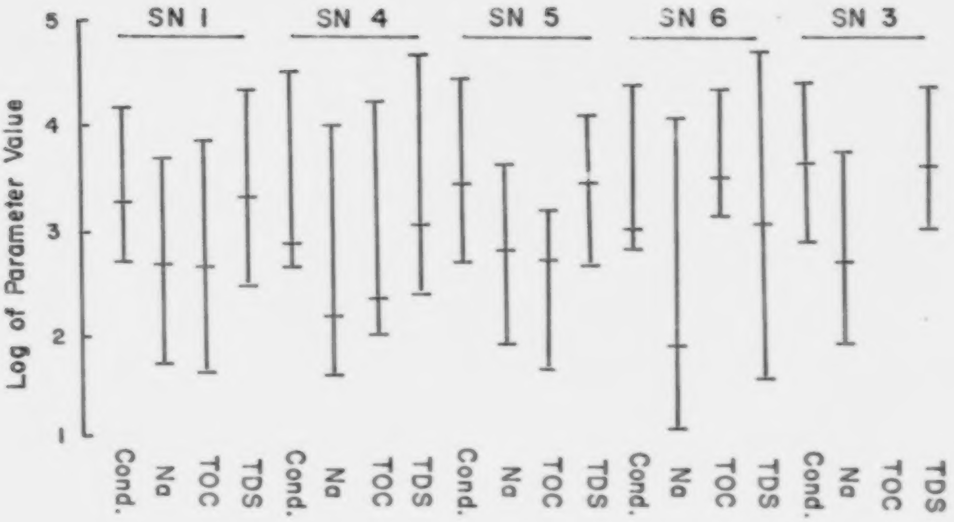


Figure 5.10 Range of Parameter Values - Crown Zellerbach Co.

of the conductivity at Station 1 varied from approximately 3 to 4.3 (1000-20,000 μmho/cm) with a median of 3.5 or 3160 μmho/cm, and similarly the logarithm of the Na concentration ranged from 2.1 to 3.75 or 126 to 5623 mg/l. As can be seen, the range of values observed at Brown varied from 8 to 630 fold and those at CZ varied from 22 to 1330 fold. The resulting wide range in the data enabled development of correlations to be used for predictive purposes for a variety of effluent conditions.

TABLE 5.4 FLOW MEASUREMENTS

Station	$\bar{Q}$ gpm	σ gpm	NOB	
Brown Co.				
4	945	341	38	Main kraft sewer
1	152	26	35	Digester
2	163	25	28	BSW
3	147	14	29	No. 8 recovery
5	328	42	34	No. 11 recovery
6	479	119	24	Causticizing
Crown Zellerbach				
1	9915	825	54	Total process
3	491	59	34	Causticizing area
4	1690	280	29	Recovery, evap + storage
5	4620	2365	23	Caustic extract + BSW
6	106	5	15	Digester

Flows determined by salt dilution or flow measuring device. $\bar{Q}$ - average, σ - standard deviation, NOB - number of observations

The field data obtained in the sampling process was analyzed using the Tufts University computer system. Regression analysis was performed to arrive at linear equations for predicting material losses from measurement of a single easily-sensed parameter. In this case, solution conductivity was chosen as the predicting parameter since it is (a) easily accomplished, (b) relatively inexpensive, (c) simple to install and maintain, (d) a reliable parameter to monitor and, (e) familiar to most mill instrumentation personnel.

Conductivity is a measure of the ability of a solution to conduct an electric current. Solutions of electrolytes conduct current by migration of ions under the influence of an electric field. It seem apparent that conductivity would be a convenient sensible parameter, since most kraft mill process streams carry varying amounts of ions; e.g. Na^+, $SO_4^=$, OH^-, Ca^{++} etc., and thus will have varying conductivities. In addition, conductivity is relatively sensitive to changes in ionic concentrations. For these reasons, the analytical data was correlated with the sample conductivity. The resulting equations are presented in Tables 5.5 and 5.6. The tables show the number of observations, the slope of the linear regression equation, the intercept, the multiple correlation and the x and y parameters. Most data correlated extremely well with correlation coefficients ranging from 0.69 to 0.99. In the case of TOC at Station 5 in Table 5.5, if values less than 100 mg/l TOC were ignored, the correlation coefficient increased to 0.69 and the intercept became negative which is more logical. That stream was clear during normal operation because it received cooling and seal waters and a discharge from a boiler feedwater demineralizer. The latter would be expected to increase conductivity but not TOC since it contained only dissolved inorganics. When high conductivities occurred they were generally due to overflows of process liquors containing organics which would consequently improve the above correlation.

TABLE 5.5 BROWN COMPANY REGRESSION EQUATIONS

$y = mx + b$

Station	NOB	Slope	Intercept	Correlation	x	y
1	64	0.2953	-65	0.951	Cond.	Na
	65	0.5198	-477	0.922	Cond.	TOC
	59	1.655	-884	0.943	Cond.	TS
	45	0.1638	94	0.971	TS	Na
2	38	0.2383	54	0.864	Cond.	Na
	37	0.5719	-62	0.987	Cond.	Toc
	33	1.743	-550	0.977	Cond	TS
	32	0.1388	120	0.888	TS	Na
3	59	0.1367	-56	0.955	Cond.	Na
	43	0.1939	145	0.693	Cond.	TOC
	40	0.5647	863	0.458	Cond.	TS
	37	0.855	181	0.333	TS	Na
5	83	0.2688	-56	0.994	Cond.	Na
	58	0.0441	319	0.314	Cond.	TOC
	21	0.3099	-117	0.693	Cond.	TOC
	59	0.8255	487	0.967	Cond.	TS
	52	0.3062	-175	0.957	TS	Na
4	52	0.2642	-9	0.965	Cond.	Na
	43	0.4803	-16	0.969	Cond.	TOC
	42	2.117	-830	0.928	Cond.	TS
	34	0.1105	114	0.942	TS	Na
7	72	0.1343	-75	0.993	Cond.	Na
	57	0.6669	2055	0.706	Cond.	TS
	50	0.902	91	0.626	TS	Na

Figure 5.11 shows plots of the equations relating sodium to conductivity for Stations 1, 2, 3, 4 and 5 from Table 5.5. The slopes of these equations are within ± 15% of their average slope indicating similar characteristics for these five sample types. In fact, when all of the data from Stations 1, 2, 3 and 4 were combined, the slope was 278.9 mg/l per mmho/cm and the correlation coefficient was 0.94. The relationship was linear because Stations 1, 2 and 3 are tributary to Station 4.

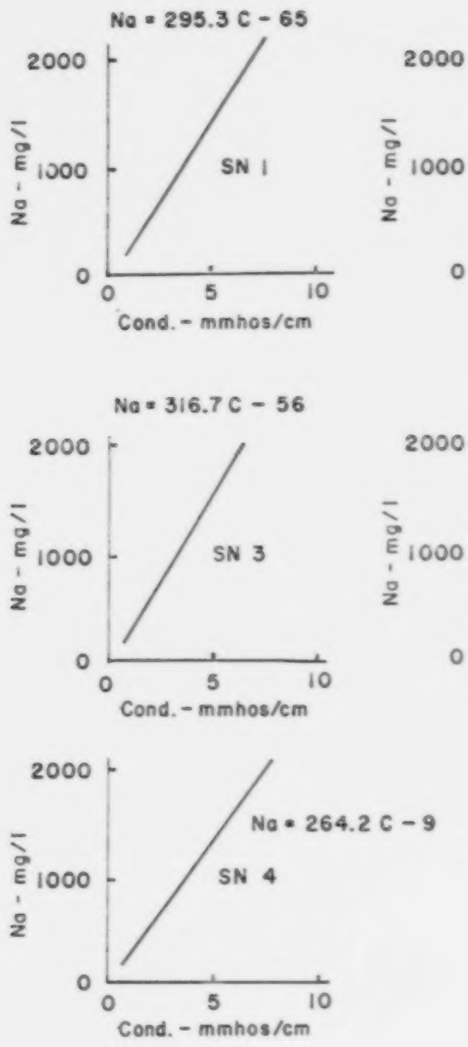


Figure 5.11 Sodium _vs_ Conductivity - Brown Co.

Figure 5.12 shows similar plots of TOC vs conductivity for the above stations. The differences in slopes represent the differences in sources contributing to the organic loads. The positive intercept and lower slope at Station 3 indicates a contribution of organics not associated with conductivity or mineral solids and such is the case as this Station receives evaporator condensates.

Table 5.6 shows the regression equations developed for the other site surveyed. Even though these two sites are widely separated geographically, differ considerably in age and arrangement of processes, and pulp different wood species under different conditions, the resulting equations are comparable and demonstrate the feasibility of developing reliable predictive equations at other mills.

Station 7 in Table 5.5 and Station 3 in Table 5.6 were located in the sewers from the causticizing areas of the mills. Although no TOC data are shown for these stations, TOC analyses were conducted but the results showed consistently low levels not related to the other parameters. This would be expected since causticizing involves large amounts of inorganic solids and no organic liquors are normally handled in these areas. In addition, the low slopes for the sodium relationships are to be expected since the normal process effluent would contain a high proportion of calcium salts and there are many ions contributing to conductivity; thus a high sodium value would indicate a spill from this area.

One potential problem with utilizing conductivity as the sensing parameter occurs in the case of a spill of nonconducting material such as soap. It is felt, however, that the majority of spills will have conducting ions associated with them and conductivity will have a high degree of reliability.

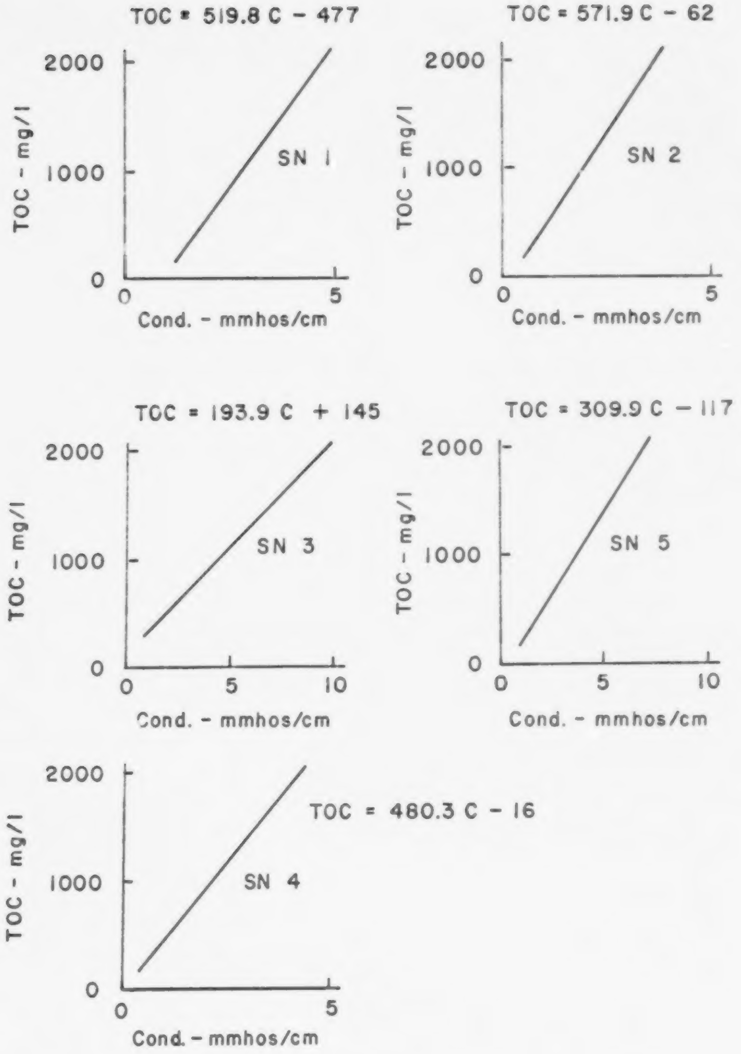


Figure 5.12 TOC vs Conductivity - Brown Co.

TABLE 5.6 CROWN ZELLERBACH REGRESSION EQUATIONS

$y = mx + b$

Station	NOB	Slope	Intercept	Correlation	x	y
1	123	0.2783	-28	0.940	Cond.	Na
	79	0.4123	-404	0.902	Cond.	TOC
	47	1.388	-989	0.962	Cond.	TS
	47	0.1923	174	0.961	TS	Na
4	108	0.2847	-60	0.974	Cond.	Na
	73	0.4806	-415	0.880	Cond.	TOC
	62	1.468	-926	0.953	Cond.	TS
5	65	0.1584	211	0.974	Cond.	Na
	48	0.2558	-71	0.841	Cond.	TOC
	43	0.4229	1720	0.856	Cond.	TS
6	30	0.4234	-291	0.995	Cond.	Na
	18	0.8396	747	0.996	Cond.	TOC
	23	0.845	-1518	0.962	Cond.	TS
3	78	0.1874	-81	0.832	Cond.	Na
	41	0.6918	65	0.789	Cond.	TS

CONTINUOUS SENSOR EVALUATION

Conductivity

Two basic types of conductivity monitors are commercially available. The first employs a sensor having two metal or carbon plates or electrodes firmly fixed relative to each other. These are contained in an insulating chamber which serves to isolate a portion of the sample. The measurement is independent of sample volume and proximity to other surfaces. The second type is referred to as electrodeless and consists of two toroidal coils arranged such that the measured solution couples the two coils. Both types of sensors employ similar types of electronics for readout, usually a direct reading meter for continuous indication of conductivity in the case of a monitor. In addition, temperature compensation is generally provided to correct conductivity readings to the standard temperature of 25°C.

As part of the LCS project, an electrodeless conductivity sensor with associated meter and recorder has been used to monitor conductivity in various process sewers. Although electrodeless conductivity probes have been available for some time, they have not been widely used in the industry. Instead, the electrode type of conductivity cell has been chosen for monitoring and laboratory work because of its familiarity and lower cost.

The electrodeless conductivity sensor is of interest because there are no electrodes exposed to the solution being measured. Thus, there is no need to replatinize or clean electrodes. Also, maintenance requirements should be less and the sensor should be able to withstand a variety of environments, because the material exposed to the solution is an inert housing.

A Balsbaugh electrodeless conductivity monitor was purchased and installed in various kraft process sewers. Conductivity was recorded over long periods of time and was found to track process operations and spills. In one case, over a period of several weeks, a coating built up on the sensor but did not effect the reading obtained as noted by checks with a laboratory electrode type cell and meter. The sensor was cleaned and reinstalled in a sewer emanating from the causticizing process. This sewer has been historically difficult to monitor due to the severe conditions existing there, particularly the high pH and the abrasive nature of the suspended solids. Previous installations of conventional sensors had been generally unsuccessful even with daily maintenance, calibration and cleaning. However, the electrodeless sensor remained clean and tracked the conductivity as determined by periodic calibration checks and required no maintenance over a period of a month. The conductivity record showed time and frequency of mud dumps and enabled detection of faulty instrumentation on a dregs washer which was resulting in high sewer losses.

At one mill, because of sometimes severe conditions existing in the sewers, sensors are placed external to the sewers and a sampling and backflushing system, as shown in Figure 5.13, is used to continuously bring a sample to the sensor and periodically backflush the system. Motive force is provided by mill water flowing through the eductor which can provide a suction lift up to 20 feet, bringing a sample of the sewer contents past the probe. The timer operated solenoid valve is periodically closed thus causing mill water to flow down the sample leg, backflushing the probe and sample line. The solenoid timer could be set to backflush every hour for 30 seconds, for example, and would also serve as a rough calibration, assuming the mill water supply to be of relatively constant composition. In addition, this arrangement provides for ease of probe maintenance since the sensor is out of the sewer and can be isolated easily.

Sodium

Specific ion monitors are commercially available to measure a variety of ions. Because sodium (Na^+) is a common constituent of kraft process liquors (which, if monitored, would reflect abnormal losses of these liquors), an Orion sodium specific ion monitor was purchased and installed to monitor kraft effluents.

A schematic of the basic monitor system is shown in Figure 5.14. The sample is pumped from the sewer to the monitor sample filter at 1-2 gpm and 20-30 psig. The monitor sample pump takes approximately 10 ml/min from the filter with the remainder serving to wash the filter surface and is then

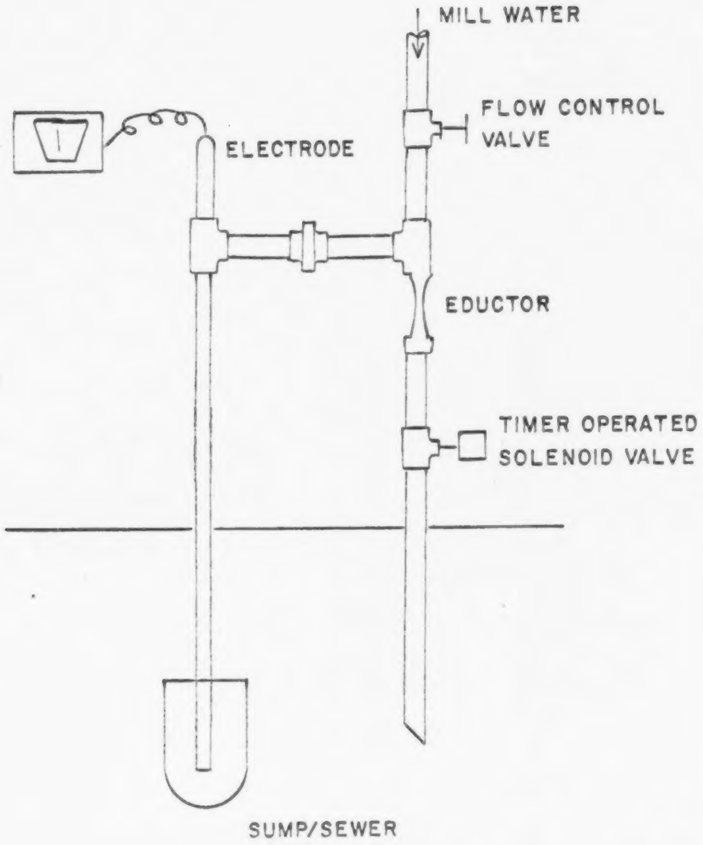

MILL WATER
FLOW CONTROL VALVE
ELECTRODE
EDUCTOR
TIMER OPERATED SOLENOID VALVE
SUMP/SEWER

Figure 5.13 Conductivity Sampling/Monitoring Scheme

5-29

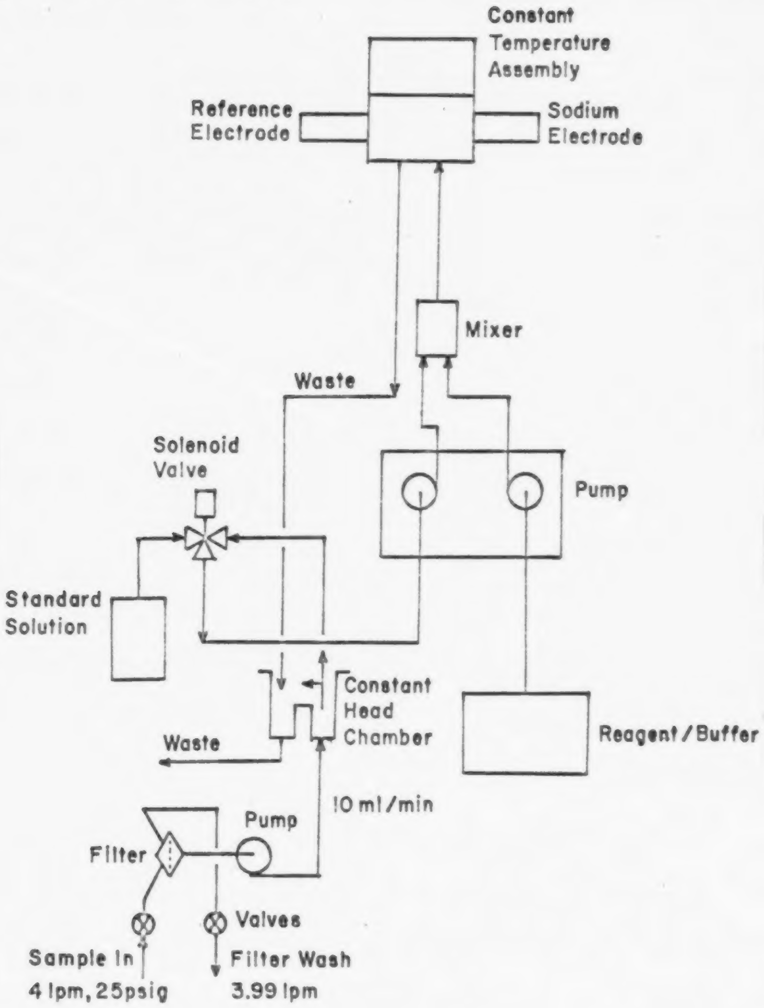

Constant
Temperature
Assembly
Reference
Electrode
Sodium
Electrode
Mixer
Waste
Solenoid
Valve
Pump
Standard
Solution
Constant
Head
Chamber
Waste
Reagent / Buffer
10 ml/min
Pump
Filter
Valves
Sample In
4 lpm, 25psig
Filter Wash
3.99 lpm

Figure 5.14 Sodium Monitor Flow Schematic

returned to the sewer. The monitor sample pump delivers the sample flow to a constant head chamber. The sample is then drawn through a two-way solenoid valve by a peristaltic pump and delivered to a mixing chamber where a reagent/buffer is mixed with the sample. The buffered sample is then pumped to the temperature controlled assembly which houses the sodium ion-specific electrode and the reference electrode. Sodium concentration is sensed and the electronics both display and record this concentration.

Thus, the monitor consists of three essential subsystems; the sample and fluid handling system, the electrode sensing system, and the power supply and electronic system. All components and reagents, except the auxiliary power supply and the filter, are housed in an industrial cabinet measuring approximately 2.5 ft wide, 4.4 ft high, and 1.4 ft deep.

The electrodes used in this application consisted of sodium sensing and iodide reference solid state electrodes which can be calibrated over two decades of concentration. Calibration over a range of 10-1000 mg Na/l was performed in this application. Calibration can be manual or automatic by switching the solenoid valve to pump a standard through the electrode assembly. In the automatic mode, calibration occurs once in a 24 hour period. The meter is then automatically restandardized by a calibration motor which drives a potentiometer to bring the meter pointer to the calibration point, usually center scale.

In order to deliver sample to the monitor, a pump capable of delivering 10 gpm at 30 psig is required. Because the monitor must receive a clean sample, that is a sample free of suspended solids, it is necessary to include some device to precondition or preclean the sample prior to the filter associated with the monitor. A standard Y-strainer was recommended by Orion for this application.

Figure 5.15 shows a flow schematic of the entire system as recommended by the manufacturer and as initially employed. Sample is pumped from the sewer at 5-10 gpm; 1-2 gpm is passed by the Y-strainer to the monitor with the remainder of the sample serving to flush the Y-strainer. Of the 1-2 gpm going to the monitor's ultrafilter, approximately 10 ml/min is taken by the monitor with the remainder serving to wash the surface of the ultrafilter. The ultrafilter requires a stream having particles that will pass a 1/32 inch screen and the ultrafilter will then remove essentially all suspended solids. This is necessary since the tubing and fluid passages are of small diameter, in the range of 0.1 inches.

The monitor was initially installed at a mill in the northeast sampling total kraft mill effluent. Problems with the sampling system external to the monitor immediately became evident. The entire sampling system including the pump became plugged and the system could not be operated continuously due to the high suspended solids content of that sewer. Attempts to alleviate this problem through installation of an improvised basket strainer on the pump suction were unsuccessful. Continuous operation was not achieved and the sample pump eventually became inoperative because it was not feasible to have full time personnel maintain the system. The original pump was one that was on hand and was used while awaiting delivery of one specific for the project. For these reasons; i.e., unavailability of full time personnel and need for a new pump, it was decided to ship the monitor to Crown Zellerbach for use during the on-site mill survey program where NCASI personnel would be available to service the system.

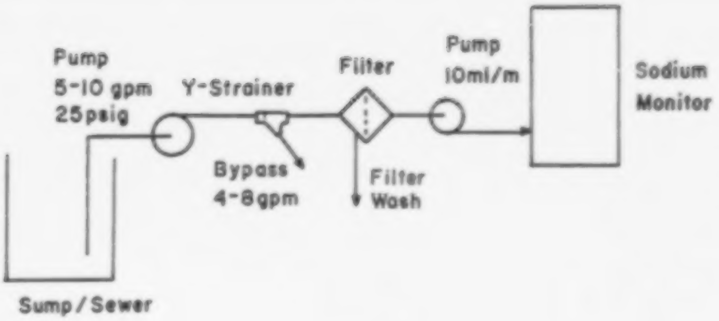

Pump
5-10 gpm
25psig
Y-Strainer
Filter
Pump
10ml/m
Sodium
Monitor
Bypass
4-8gpm
Filter
Wash
Sump/Sewer

Figure 5.15 Original Sodium Monitor Sampling System

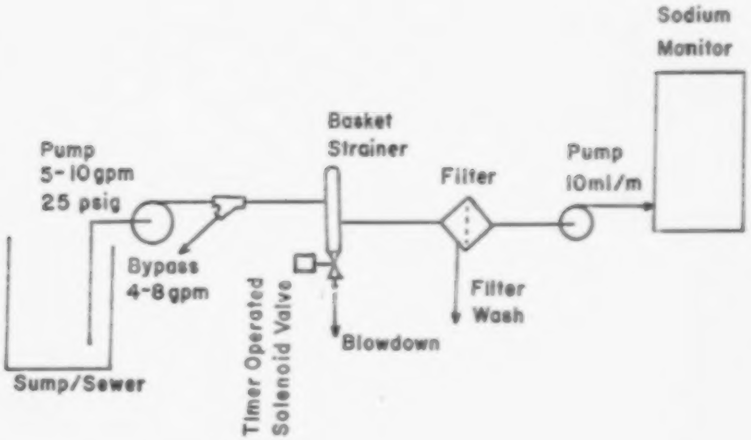

Sodium
Monitor
Basket
Strainer
Pump
5-10gpm
25 psig
Filter
Pump
10ml/m
Bypass
4-8gpm
Filter
Wash
Blowdown
Timer Operated
Solenoid Valve
Sump/Sewer

Figure 5.16 Modified Sodium Monitor Sampling System

A new pump was selected to meet the conditions necessary for the installation, that is, 10 gpm centrifugal at 30 psig with an open impeller. The monitor was installed at the pulp mill sewer and, despite many attempts to alleviate the problem, the sampling system prior to the monitor could not be kept from plugging. The system operated for short periods and required constant attention. Thus, it was decided to move the monitor to sample the effluent from the pulp mill primary clarifier. Although this would only give historical information of mill operation, because of clarifier retention time, it would provide information on the operation of the sodium monitor. The monitor had performed satisfactorily in the other installations, but because of the sampling difficulties, no long term operational experience had been obtained.

The sampling system, which is shown schematically in Figure 5.16, was devised, put together, operated and maintained by Mr. J.W. Wenger of CZ, who also did much of the operation and maintenance of the sodium monitor. Sample was pumped from the primary clarifier effluent and through an 80 mesh pressure screen prior to the Orion ultrafilter. The pressure screen was equipped with a timer operated solenoid valve which allowed blowdown of the screen every 17 minutes for 10-15 seconds. In order to continuously run, it was necessary to remove and clean the screen daily.

The ultrafilter consists of a 0.75 by 12 inch cellulose acetate type of membrane which was embedded in a two piece plastic block, the two halves of which are bolted together. A series of parallel grooves are scribed in the bottom half of the block and the filter is placed over the grooves. Sample flows in the space above the filter at about 1 gpm, and the accepted sample flows in the grooves at about 5-10 ml/min and is then pumped to the monitor. The large flow over the surface of the filter serves to wash it. It was found during the operation of the monitor that the life of the filter depended on the pressure at the filter. Twenty psig gave only 3 days of operation before it was necessary to change the filter. Thirty psig resulted in a 10-15 day life as long as 1 gpm was going past the filter and the accepted flow was 5-10 ml/min. The type of material which accumulated on the filter and eventually plugged it appeared to be resinous such as tall oil or pitch.

After the sampling problems had been overcome, the monitor was operated for about 1500 hours over a six month period. Because of the sampling system problems, it was not feasible to operate continuously during periods when no one was available to check the system.

The monitor itself functioned extremely well during the operational period. An example chart is shown in Figure 5.17. The charts reflected operating conditions within the mill showing periods of upset and shutdown. The monitor did not fail to automatically restandardize itself after periods of running dry, freezing, malfunctions of other parts of the system or in normal operation. Periodic calibration checks with standards other than the center scale standard showed good agreement as did comparisons with sodium measurements by other methods.

All components of the monitor within the industrial enclosure performed satisfactorily. As can be seen from the diagrams, the system requires three pumps; one to pump sample from the source to the monitor, one to pump the accepted flow from the ultrafilter to the constant head chamber and one to pump sample from the constant head chamber and reagent from the reagent reservoir to the mixer and thence to the sensors. The latter two pumps are

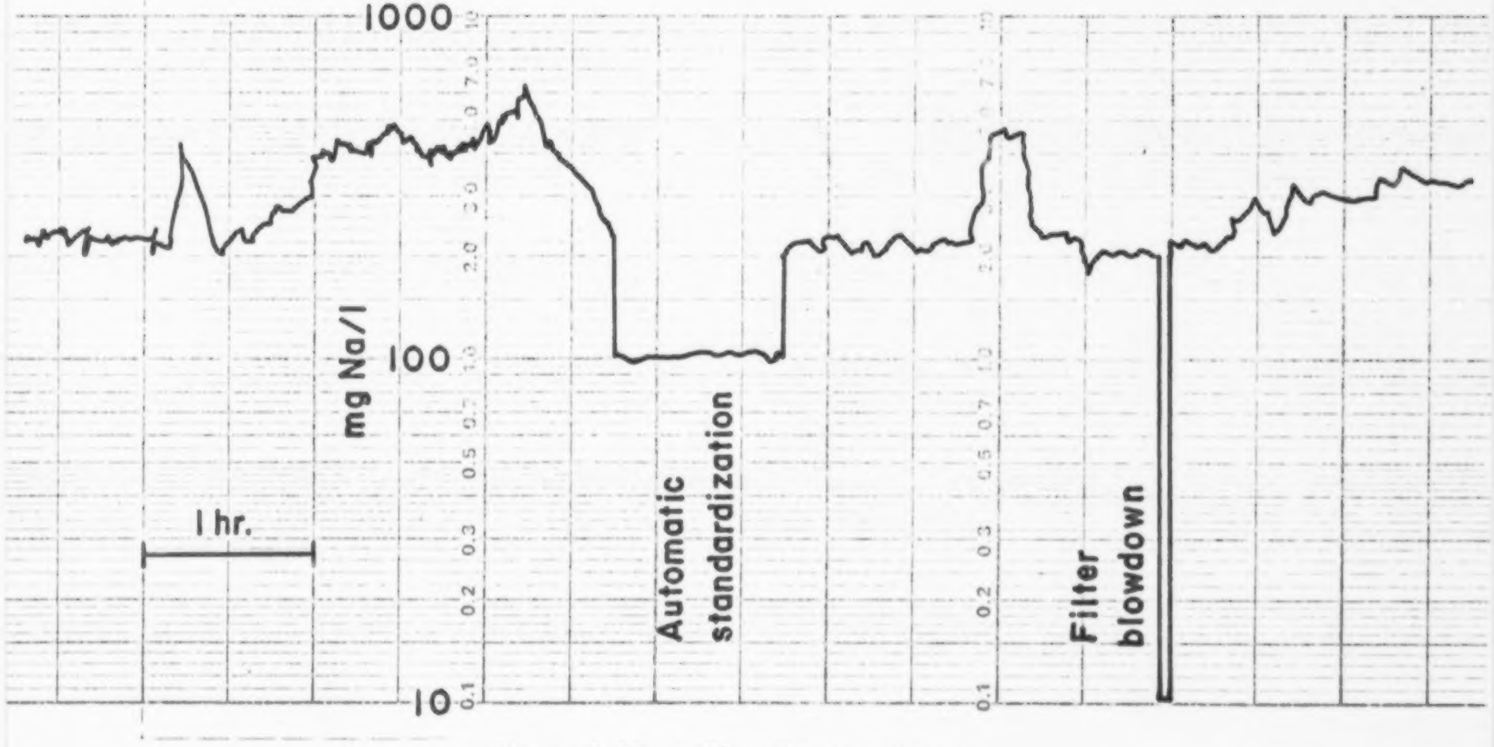


Figure 5.17 Sodium Monitor Chart

supplied as part of the monitor with the first being a plunger pump and the second a peristaltic pump. The peristaltic pump tubing has a definite life and, in this application, was found to last 300 to 500 hours before it became worn and ruptured, requiring replacement.

Concentration is displayed on a panel meter which shows instantaneous concentrations and by a strip chart recorder. The response time of the system was found to be 3 to 5 minutes. This was determined by spiking the sample at the inlet to the ultrafilter and is believed due to residence of fluid in the system. The strip chart recorder, however, only allowed viewing four hours of data. Unwinding earlier data proved to be a major operation. A recorder with a folding chart allowing easy access to the chart would have been desirable. In addition, because the chart scale is logarithmic it was difficult to read. Integrated readings would have been more useful. Provision is made for high and low concentration setpoints and alarms and an optionally available converter board allows a standard output; e.g., 10-50 ma, which could then be converted to a digital signal for recording and this would be useful in the computerized loss control strategy. The results could then be printed as time averages or integrated with a flow device signal to report mass of sodium per unit time.

In summary, the sodium monitor was found to be a reliable instrument; however, the sampling system, which is not a part of the monitor, proved to be the bottleneck in the operation and this problem would be expected with any instrumentation which requires an off-stream, clean sample, particularly in industrial sewer monitoring and in particular in the pulp and paper industry where variable quantities and sizes of suspended solids are apt to be in the sampled stream. This would apply to other monitoring instrumentation other than specific ion such as TOC and TOD. Instrument manufacturers provide reliable sensing systems and electronics but the problem of sampling and sample conditioning requires further work.

Color

A study was conducted to compare continuous monitor measurement of true color of pulp and paper mill process sewers with the standard method of color measurement. The study was conducted by Dr. R.C. Whittemore, NCASI Research Engineer. The color of both treated and untreated process sewers was evaluated. The study was conducted at a mill which had installed a monitor package on its final effluent which included color, total organic carbon, pH, turbidity and conductivity. The mill, designated as Mill A, is an integrated bleached kraft mill employing primary settling, activated sludge, and secondary settling for treatment before discharge to the receiving water. The monitor package continuously sampled the treated effluent.

Samples were also analyzed from several sources within a second mill, designated as Mill B. The sampling points are outlined below.

Sample 1 - 250 TPD bleached kraft mill effluent
Sample 2 - 700 TPD unbleached kraft mill effluent
Sample 3 - Combination of Sample 1 and Sample 2 going to primary clarification
Sample 4 - Sample 3 after primary clarification
Sample 5 - Sample 4 after secondary treatment

The instrument used in the study was the Dupont Model 400 Photometric Analyzer. The general purposes of the study were to: (1) assess the ability of this instrument to measure true color as defined by NCASI Technical Bulletin No. 253 (1). True color is there defined by comparison to a chloroplatinate standard following filtration through a 0.8 micron filter and pH adjustment to 7.6, (2) assess the impact of suspended solids and pH variation on color measurement with this instrument.

A brief description of the instrument and its principle of operation is included in the next paragraph. A more detailed sales bulletin is referenced (2).

The Dupont Model 400 Analyzer uses a split light beam and measures the difference in absorption of radiation by the sample at two wavelengths in the UV-visible energy spectrum. The light beam passing through the sample is split into two beams. One beam is directed toward the measuring wavelength phototube through an optical filter which excludes all wavelengths except the measuring wavelength. The measuring wavelength is one that is strongly absorbed by the species being measured. The other light beam is directed toward a reference wavelength phototube. The reference wavelength is one at which the light is weakly absorbed by the measuring species compared to the light at the measurement wavelength. The phototubes convert both light signals to electrical signals proportional to the light in each beam. The logarithm of each beam's intensity is then compared to provide one output signal that is linearly proportional to the concentration in the sample. This linearity of absorbance-concentration is an expression of Beer's Law.

A comparison was made of the effluent color as determined by both the monitor and the standard method. These tests were conducted over a several day period with treated effluents from two kraft mills. A majority of the data was obtained, however, using only one of the effluents (Mill A). A limited comparison using sample 5 from Mill B is also included. Lower color concentrations, less than 800 platinum-cobalt color units (pcu) were obtained by diluting this effluent with tap water and pumping it through the sampling system.

The results are presented in Figure 5.18 as Instrument Color vs. True Color. A linear regression analysis was performed upon these data and the results presented in Figure 5.18 as well. The correlation coefficient, r^2, was 0.91. Of the 46 separate comparisons made, 27 showed instrument color values greater than the true color.

Some additional characteristics of the effluents used in this comparison appear in Table 5.7.

TABLE 5.7 CHARACTERISTICS OF SECONDARY EFFLUENTS USED IN COLOR COMPARISONS

pH	6.8-7.1
Suspended Solids	50-75 mg/l
Conductivity	1000-1500 µmhos/cm
Turbidity	75-200 JTU
True Color	800-1000 PCU

Samples taken internal to both Mills A and B were gathered for a similar color comparison. The results in Table 5.8 and Table 5.9 refer respectively to Mill A caustic and chlorine stage bleaching effluents.

TABLE 5.8 COLOR MONITOR MEASUREMENT OF MILL A CAUSTIC STAGE BLEACHING EFFLUENT

	Color, PCU		Percent
pH	Instrument	True	Difference
9	1000	980	+2
9	1010	975	+4
9	545	600	-9
9	985	940	+5
9	1050	920	+14
9	990	940	+5
9	985	935	+5

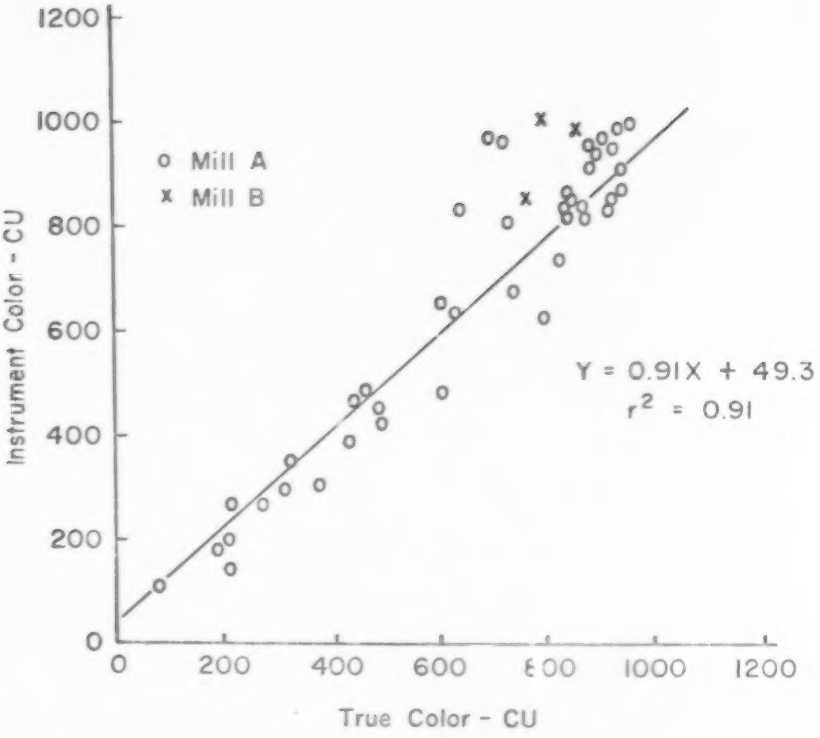


Figure 5.18 Instrument Color *vs* True Color

5.40

TABLE 5.9 COLOR MONITOR MEASUREMENT OF MILL A CHLORINE STAGE BLEACHING EFFLUENT

	Color, PCU		
pH	Instrument	True	Percent Difference
1.8	360	1450	-303
1.8	330	1400	-324
1.8	345	1390	-303
1.8	320	1340	-308

The results in Table 5.8 are presented without comment since they reveal nothing unusual in view of what was learned from the data in Figure 5.18.

The instrument-true color comparison for the chlorination stage bleaching effluent presented in Table 5.9 indicates large errors between instrument and true color determinations. The instrument probably cannot compensate for the known shift in absorbance of kraft mill effluents with large pH changes.

The total mill secondary treated effluent from Mill A was then passed through the color monitor following pH alteration in the 4-10 range. The results are presented in Table 5.10.

These results show that pH variation for this particular effluent was not always a significant factor. This result cannot be extended to all kraft mill effluents since the absorbance-pH relationships may vary. Also, the bulk of the work to date shows a pH-color effect although it has not been mathematically quantified (1).

The effect of suspended solids on color monitor measurement was evaluated for the secondary effluent discharged to the receiving water at Mill A. This effluent contained about 50-75 mg/l of suspended solids. As indicated by Figure 5.19, these suspended solids levels did not influence the monitor measurement of color. Combined primary-secondary sludge was then added to

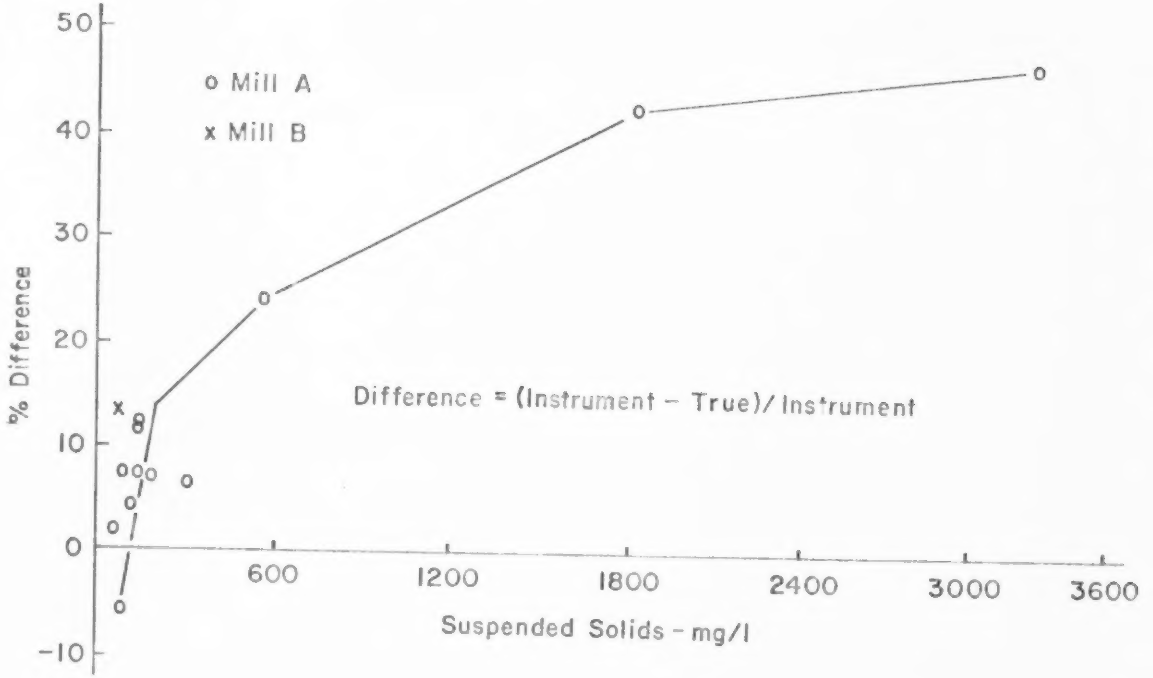


Figure 5.19 Influence of Suspended Solids on Instrumental Color Measurement

5.42

this effluent in controlled amounts to produce higher suspended solids levels. The measurement comparison with these samples is also shown in Figure 5.19, where the percent difference vs. suspended solids levels is plotted. Deviations of 20% and larger do not occur until suspended solids concentrations of 600 mg/l and greater occur in the monitored effluent.

TABLE 5.10 EFFECTS OF PH VARIATIONS OF TOTAL MILL EFFLUENT ON COLOR MONITOR MEASUREMENT

pH	Color, PCU Instrument	 True	Percent Difference
5.2	770	605	+27
4.7	765	790	-3
4.0	895	805	+11
6.1	955	930	+3
6.5	965	930	+4
6.1	930	895	+4
8.2	970	935	+4
8.4	950	900	+6
8.6	1115	1040	+6
9.1	1070	1165	-8
9.4	1195	980	+22
10.2	1065	985	+19
9.7	945	940	0

Additional information regarding color monitor measurement and suspended solids effects was obtained using Mill B samples. The samples obtained from sampling point 5 have already been presented in Figure 5.18. Analyses from the remaining sample points are given in Table 5.11. The samples were composites from four separate days.

The nature of the suspended solids particles in sample 2 and 3 were observed to be black fly ash material from a bark boiler. These materials, being opaque, will strongly absorb light and give the appearance of higher color in the instrumental analysis. The rather poor correlation of instrument to true color with these effluents is probably related to the presence of these suspended solids.

TABLE 5.11 INSTRUMENT VS TRUE COLOR COMPARISON FOR MILL B

Sample	pH	Suspended Solids, mg/l	Color, PCU Instrument	Color, PCU True	Percent Difference
1	3.6	-	1135	980	+14
1	3.9	37	945	890	+6
1	3.8	-	1020	450	+56
1	3.6	196	555	610	-10
2	10.0	362	830	360	+231
3	7.1	98	1310	630	+208
3	6.9	-	1695	760	+55
3	8.1	234	1185	510	+57
4	8.5	-	1670	690	+59

The data from these two sources suggests that the use of the color monitor on an effluent with a given particle type can result in a good correlation with true color measurements. If the solids concentrations and nature vary, the correlation may fail.

In summary, the Dupont Model 400 Photometric Analyzer can be used to accurately monitor true color concentrations of kraft mill secondary treated effluents. Fluctuations in effluent pH in the range 4-10 did not cause appreciable errors in the monitor measurement of color. However, the effect of effluent pH on the monitor's performance depends upon the change in absorbance at the measuring wavelength following pH changes. The monitor did not track color in the chlorination stage effluent where the pH was 1.8. On the other hand, the caustic stage bleaching effluent at pH 10 was monitored accurately for true color.

The presence of suspended material in secondary treated effluents in the range of 0-300 mg/l resulted in monitor color measurements no greater than 14% higher than the corresponding true color measurement. Monitor errors increased markedly at suspended solids levels above 300 mg/l. The presence of opaque suspended materials, such as black fly ash particles, resulted in poor monitor performance. When these particles were present in an effluent, the color monitor gave concentrations as much as 200% higher than the true color concentration.

Other Parameters

In addition to the parameters which were selected for continuous sensor evaluation, others could be selected for continuous monitoring to detect spills. These would include temperature, pH, oxidation/reduction potential (ORP or redox), turbidity, other organic indicators such as oxygen demand (TOD) and other specific ions.

Temperature would be useful where a hot process liquor may spill into a normally cool effluent and this parameter is used by Brown Co. to detect spills from the white liquor clarifier and mud washing area. The measurement is not quantitative in terms of chemical loss and specific only in particular areas.

Hydrogen ion concentration or pH may be useful in developing a LCS since many of the process liquors are alkaline; however, this would not be a quantitative measurement and it is felt that pH would also be relatively insensitive particularly in the case where the normal sewer flow is buffered in the alkaline range. Similarly, redox may not be quantitative. These three parameters, temperature, pH and ORP, have been used by many industries for monitoring and process control and it did not seem necessary or desirable to evaluate them as sensors in this program.

There are a variety of devices available for measuring and monitoring turbidity; however, because of the nature of the flows being monitored in this program; i.e., containing mainly dissolved as opposed to suspended solids, highly colored, alkaline and containing materials which may coat or etch glass, turbidity does not appear to be an applicable parameter. It should be pointed out that where suspended solids are of major concern, such as in a paper mill, that optical density or turbidity may be a useful parameter to alarm personnel that systems losses are occurring.

Instrumentation is available for measuring organic material, such as carbon content or oxygen demand. Some of these have been evaluated by NCASI and industry personnel and they are discussed in NCASI Technical Bulletin No. 256. In general, it would appear that this type of instrumentation would be too expensive to install in a process loss control monitoring system. Similarly, specific ion monitors would be in the same category; i.e., too costly for multi-point monitoring. The concept of specific ion monitoring is, however, applicable to a spill detection system in the pulp and paper industry, since the process liquids contain various ions which, if detected above definable levels would indicate the loss of specific materials. The use of some specific ion electrodes in pulp and paper industry effluents has been evaluated and is discussed in NCASI Technical Bulletin No. 241.

REFERENCES

1. "An Investigation of Improved Procedures for Measurement of Mill Effluent and Receiving Water Color," National Council for Air and Stream Improvement, Technical Bulletin N-. 253, NCASI, New York, NY, 1971
2. Bulletin 420-A, E.I. Dupont de Nemours & Co., Inc., Instrument Division, Wilmington, Delaware

SECTION 6

DEVELOPMENT OF LOSS CONTROL STRATEGIES

In order to design a loss control system and arrive at a loss control strategy, it is necessary to quantify the nature and frequency of intermittent process losses. The techniques include actual measurement, estimation based on engineering judgment and experience or more generally, through the use of a combination of these techniques.

The ideal approach would be to determine those areas in which the most concentrated losses are generated and then group those areas according to type of material generated. For example; black liquor generation areas such as digestion, brown stock washing, evaporation and recovery; cooking liquor or high inorganic content liquor generation areas such as causticizing, mud washing, white and green liquor storage and smelt tanks; and high organic, low inorganic areas such as soap storage and tall oil production.

These areas would then be examined more closely. Relatively clean flows, such as seal waters, should be segregated to prevent dilution of recoverable materials and to obviate low concentration, high flow discharges. The process sewers and drains from these areas would then be monitored and their flows and characteristics determined over a sufficiently long period of mill operation to include startups, shutdowns and normal operation in order to determine relative frequencies and amounts of spills and their chemical characteristics.

A minimum analytical program would be designed to continuously measure flow and conductivity from the liquor handling areas. More extensive analysis would include sampling and determination of such constituents as sodium, BOD and solids to assess the magnitude of losses and to possibly correlate these constituents with conductivity since the latter is easily and economically monitored and is directly related to the concentration of inorganics in these discharges. The organic content of the same discharges is generally related to the inorganic content.

Flow measurement is essential in order to determine the mass of the various constituents to assess the economic impact of their recovery. Continuous monitoring of flow will also provide quantitative information necessary to size sumps, pumps, pipes and tankage or storage capacity.

When both flow and conductivity are monitored, a useful parameter to indicate spills is the product of flow times conductivity. The simple product of flow times conductivity may, however, reflect a high flow, low conductivity situation. A better indicator would be the product of the correlation with conductivity of a parameter of direct interest times the flow. The latter would directly reflect material losses. Data collection can be facilitated using electronic data loggers and tape storage. Data can then be analyzed using conventional computer program packages.

The data should be analyzed to rationally design a loss control system and strategy. A useful technique is the use of a model and such an approach will be described.

Modelling Using Actual Data

A number of modelling techniques are available to simulate the conditions in a mill using high speed digital computers. These models take as input the data obtained from monitoring process sewers and can be programmed to arrive at recovery tank size, pumping rates, amount of material recovered and sewered, etc.

This has been done for purposes of this report using DYNAMO (Dynamic Simulation Modelling)(1). Four versions of one basic model written for DYNAMO were used to consider various loss control strategies. Each version has a basic design; i.e., four sumps monitored for flow and conductivity and equipped with pumps to intercept high strength material losses and pump them to a tank from which the intercepted wastes can be pumped to the recovery system at a controlled rate. Flows are intercepted at the sumps based on a conductivity setpoint or a mass setpoint (flow times conductivity).

The programs have been written with various constraints. The maximum size of the spill tank can be specified and, when the volume reaches this maximum, material will not be pumped from the sumps unless it is more concentrated than that which is presently in the spill tank. During the time that the tank is full, material will be pumped out of the spill tank to the sewer to make room for the more concentrated material.

Material is continously pumped from the spill tank to recovery as long as three conditions are met: 1) recovery has volume available; 2) the material exceeds a setpoint for acceptability to recovery and; 3) the spill tank contents are above a minimum volume.

Figures 6.1 and 6.2 are flowcharts of the general logic used to turn the sump pumps on and to turn the recovery pump on, respectively. Various parameters, such as setpoints, rate of pumping to recovery, minimum and maximum spill tank volume and input flows and conductivities, can be changed during runs of the model.

6.4

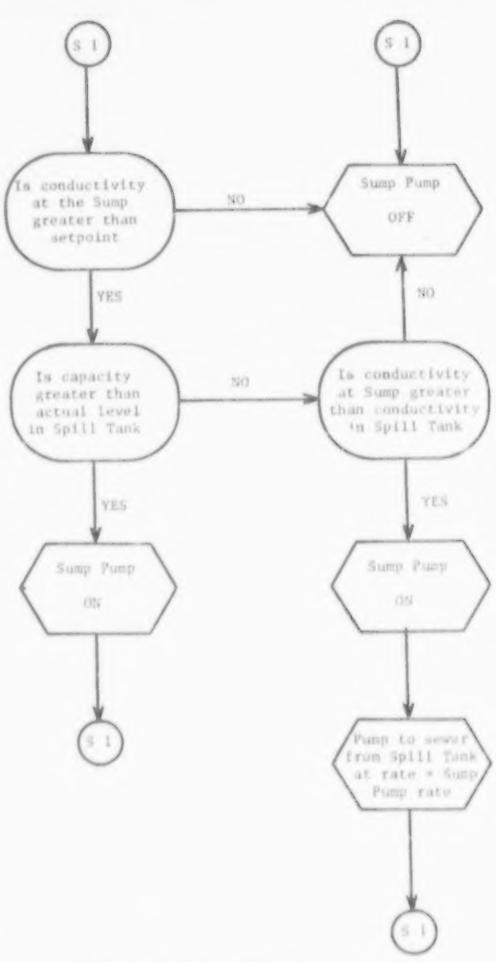

S 1
Is conductivity at the Sump greater than setpoint
NO
YES
Sump Pump OFF
S 1
Is capacity greater than actual level in Spill Tank
NO
YES
Is conductivity at Sump greater than conductivity in Spill Tank
NO
YES
Sump Pump ON
S 1
Sump Pump ON
Pump to sewer from Spill Tank at rate = Sump Pump rate
S 1

Figure 6.1 Sump Pump Logic

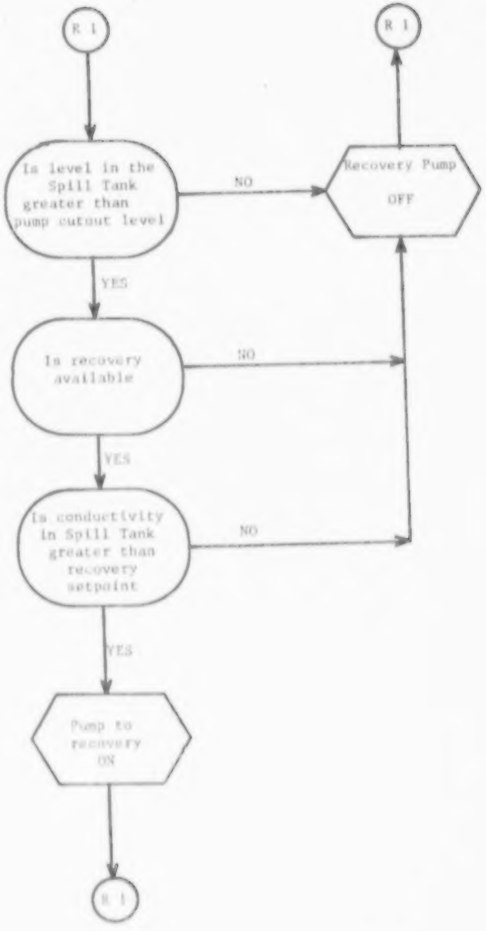

R 1
Is level in the Spill Tank greater than pump cutout level
NO
YES
Recovery Pump OFF
R 1
Is recovery available
NO
YES
Is conductivity in Spill Tank greater than recovery setpoint
NO
YES
Pump to recovery ON
R 1

Figure 6.2 Recovery Pump Logic

6-5

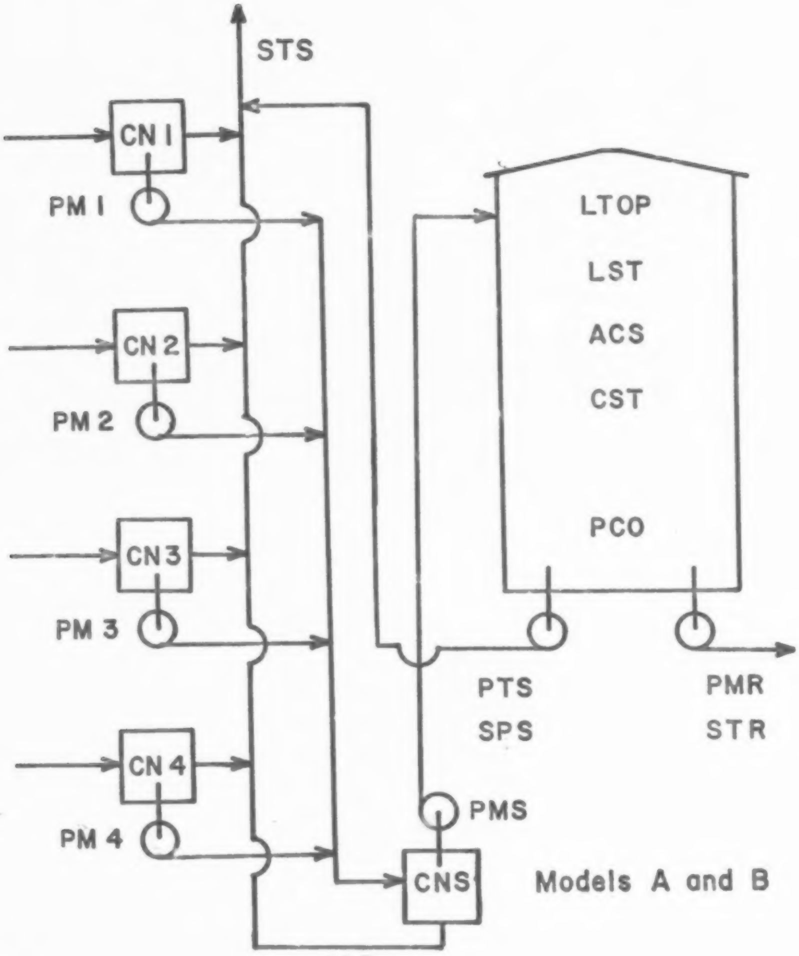

STS
CN 1
PM 1
CN 2
PM 2
CN 3
PM 3
CN 4
PM 4
LTOP
LST
ACS
CST
PCO
PTS
SPS
PMR
STR
PMS
CNS
Models A and B
SRS

Figure 6.3 Schematic Representation of Models A and B

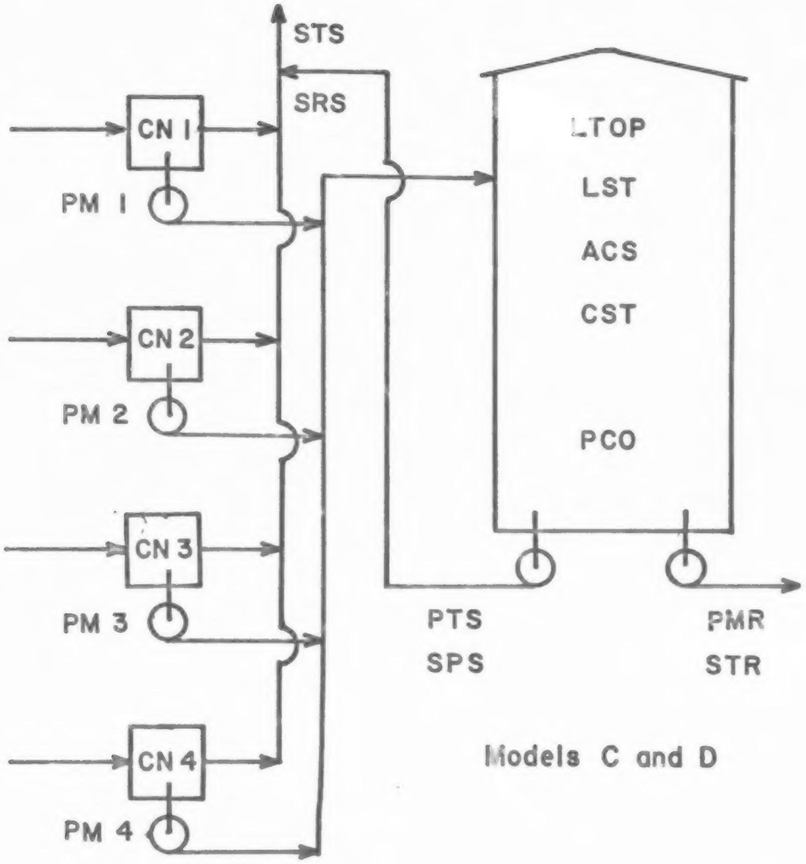

STS
SRS
CN 1
PM 1
CN 2
PM 2
CN 3
PM 3
CN 4
PM 4
LTOP
LST
ACS
CST
PCO
PTS
SPS
PMR
STR
Models C and D

Figure 6.4 Schematic Representation of Models C and D

Schematics of the four versions of the basic model are shown in Figures 6.3 and 6.4. Only two schematics are shown since Models A and B and Models C and D differ only in their computational procedures and not in their basic physical structure.

The Model A strategy combines the four sumps into a common sump using mass setpoints based on the product of flow times conductivity to divert the individual sumps to the common sump. If the spill tank is full but the conductivity at the individual sumps exceeds the conductivity in the spill tank, the individual sumps will still be diverted to the common sump; otherwise they go to the sewer. The common sump is then pumped to the spill tank if the conductivity at the sump exceeds the conductivity in the spill tank. If the spill tank is full but the conductivity at the common sump exceeds that in the spill tank, material will be pumped to the spill tank and the spill tank contents will be pumped to the sewer in order to concentrate the spill tank contents.

The material in the spill tank will always be pumped to recovery as long as three conditions are met: 1) recovery can accept material, 2) the conductivity of the spill tank contents exceeds a setpoint for acceptability to recovery, and 3) the spill tank contains more than a specified minimum volume.

Figure 6.5* is a printout of two case runs of the Model A strategy. In the first case, the spill tank is of unlimited size and in the second case, the maximum spill tank volume is 10,000 gallons. Table 6.1 defines the symbols and abbreviations in this and subsequent printouts. Table 6.2 summarizes the results of the two cases.

* Figures 6.5 starts on page 6-24, 6.6 on page 6-32, 6.7 on page 6-38 and 6.8 on page 6-46

TABLE 6.1 SYMBOLS USED IN MODEL PRINTOUTS

Symbol	Meaning
PM1,2,3,4	Sump pump rates, gpm
CN1,2,3,4	Conductivity at the sumps, µmho/cm
PMS	Pump rate to spill tank, gpm
PMR	Pump rate to recovery, gpm
LST	Level in spill tank, gallons
LTOP	Maximum level in spill tank, gallons
PCO	Recovery pump cutout level, gallons
ACS	Amount of solids in spill tank, gal*(µmho/cm)
CST	Conductivity in spill tank, µmho/cm
STR	Solids to recovery, gal*(µmho/cm)
STS	Solids to sewer, gal*(µmho/cm
PTS	Pump rate to sewer from spill tank, gpm
SPS	Solids pumped to sewer from spill tank, gal*(µmho/cm)
CNS	Conductivity in sewer, µmho/cm
SRS	Solids rejected to sewer from sumps, gal*(µmho/cm)
E+O	Power of ten to be multiplied by result
T	Thousand (E+03)
M	Million (E+06)

TABLE 6.2 MODEL A RESULTS

LTOP	LST	CST	ACS	STR	STS	SPS	SRS
gal	gal	µmho/cm			gal*(µmho/cm)		
1M	57443	4425	254.2M	889M	168M	0	0
10T	997	3620	3.6M	875M	434M	47.5M	69.35M

These results and the printout show that, in the first case, a spill tank with a minimum volume of approximately 86,000 gallons would be required for this example (Case A1, Time 500). The amount of solids recovered and retained in the spill tank (STR + ACS) in this case amounted to 1143.2M gal*(µmho/cm). In the second case, where the spill tank maximum volume was limited to 10,000 gallons, solids recovered and retained amounted to 878.6M with nearly the same amount going to recovery as in Case 1 (875 vs. 889), but, because of the smaller spill tank, more solids went to the sewer in this case (434 vs. 168) and 117M of these (SPS + SRS) were pumped to the sewer from the spill tank to make room for more concentrated spills (SPS) or rejected to the sewer at the common sump (SRS) because they were less concentrated than what was already in the spill tank.

Material balances with spill tank sizes between the maximum necessary of 86,000 gallons and the case specified of 10,000 gallons would have to be arrived at with further runs of the model. Selections would be based on economics, space availability and downstream effects.

The Model B strategy combines all four sumps into one sump and pumps from that sump to the spill tank if the mass setpoint, or product of flow times conductivity, is exceeded. If the spill tank is full but the conductivity at the sump exceeds that in the spill tank, the lower conductivity material in the spill tank will be pumped to the sewer to make room for the more concentrated material. As in the other model, spill tank contents are always being pumped to recovery subject to the three constraints noted previously.

Figure 6.6 is a printout of two case runs for the Model B strategy. In the first case, the spill tank is of unlimited volume and in the second case, the maximum specified tank volume is 20,000 gallons. Table 6.3 summarizes the results of the two case runs.

In the first case, a spill tank having a minimum volume of 244,000 would be required. The amount of solids retained in the spill tank and sent to recovery (ACS + STR), in this case amounted to 1253.7M. In the second case, where the maximum spill tank volume was limited to 20,000 gallons, solids retained and recovered amounted to 530.9M. Because of the smaller spill tank in the second case, more solids went to the sewer than in the first case (738.5M vs. 60.9M) and 453.9M of these (SPS + SRS) were pumped to the sewer from the spill tank (SPS) to make room for more concentrated spills from the sump or were rejected to the sewer from the sump (SRS) because they were less concentrated than what was already in the spill tank.

TABLE 6.3 MODEL B RESULTS

LTOP	LST	CST	ACS	STR	STS	SPS	SRS
gal	gal	µmho/cm	gal*(µmho/cm)				
1.0M	221,570	2790	618.3M	635.3M	60.9M	0	0
20T	20,000	2499	50.0M	525.9M	738.5M	210.7M	243.2M

On examining the plot for the second case, it can be seen that the spill tank level (L) never decreased and that the recovery pump (R) went off at time 620 and didn't come back on. This is because the conductivity of the spill tank contents (N) decreased to the recovery setpoint of 2500 µmho/cm and no material was being pumped into the spill tank because the conductivity at the sump was less than that in the spill tank. This strategy would be modified by changing setpoints to prevent collection of material requiring more evaporator capacity than might be normally available. Setpoint selection is a function of the tank size selected as well as the evaporator system capacity.

Model C treats the four sumps individually and uses a conductivity setpoint to initiate pumping to the spill tank. If the spill tank is full but the conductivity at the individual sumps exceeds that in the spill tank, the lower conductivity material in the spill tank will be pumped to the sewer to make room for the more concentrated material from the sumps. The material in the spill tank is continuously pumped to recovery with the same constraints as in the other models.

Figure 6.7 is a printout of two case runs of Model C. In the first case, the spill tank volume is unlimited and in the second case, the maximum specified spill tank volume is 10,000 gallons. The conductivity setpoints at the sumps are 2000 µmho/cm. Table 6.4 summarizes the results of the two cases.

Table 6.4 Model C Results

LTOP	LST	CST	ACS	STR	STS	SPS	SRS
gal	gal	µmho/cm			gal*(µmho/cm)		
1M	32,882	4867	160M	957M	188M	0	0
10T	990	6194	6.13M	893M	406M	81.8M	164M

In the first case, a spill tank with a minimum volume of approximately 70,000 gallons would be required for this example (Case B1, Time 500). The amount of solids retained in the spill tank and sent to recovery (ACS + STR) in this case amounted to 1117M. In the second case where the maximum spill tank volume was limited to 10,000 gallons, solids retained and recovered amounted to 899M. Because of the smaller spill tank in this case, more solids went to the sewer than in the first case (406M vs. 188M) and 264M of these (SPS + SRS) were pumped to the sewer from the spill tank (SPS), or rejected to the sewer from the individual sumps (SRS) because they were less concentrated than what was already in the spill tank.

A comparison of the plots for the two cases shows the spill tank level

(L) to steadily increase and then steadily decrease in the first case as the material at the sumps becomes weaker. The conductivity in the tank (N) remains fairly uniform thoughout the period. In the second case, the level quickly reaches the maximum and because the system is always attempting to bring in more concentrated material by pumping the less concentrated spill tank contents to the sewer, the conductivity in the spill tank (N) fluctuates considerably. Toward the end of the run when the sumps are receiving weaker flows, nothing is pumped to the spill tank. Since the tank is always being pumped to recovery whenever possible, the level drops to the minimum specified and the recovery pump is turned off.

The Model D strategy is similar to that of Model C but uses setpoints based on the product of flow and conductivity or mass, rather than conductivity alone, to initiate pumping from the individual sumps to the spill tank. If the spill tank is full but the conductivity at the individual sumps exceeds that in the spill tank, the lower conductivity material in the spill tank will be pumped to the sewer to make room for the more concentrated material from the sumps.

Figure 6.8 is a printout of two case runs for the Model D strategy. In the first case, the spill tank volume is umlimited and in the second case, the maximum specified spill tank volume is 20,000 gallons. Table 6.5 summarizes the results of the two runs.

Table 6.5 Model D Results

LTOP	LST	CST	ACS	STR	STS	SPS	SRS
gal	gal	µmho/cm		gal*(µmho/cm)			
1M	172,000	2992	514.8M	744.4M	55.2M	0	0
20T	19,212	2325	44.7M	830.6M	439.2M	141.4M	267.7M

6 13

In the first case, a spill tank with a minimum volume greater than 172,000 gallons would be required. The amount of solids retained in the spill tank and sent to recovery (ACS + STR) in this case amounted to 1259.2M. In the second case where the maximum spill tank volume was limited to 20,000 gallons, solids retained and recovered amounted to 875.3M. Because of the smaller spill tank in the second case, more solids went to the sewer than in the first case (439.2M vs. 55.2M) and 409.1M of these (SPS + SRS) were pumped to the sewer from the spill tank (SPS) to make room for the more concentrated spills from the sumps or rejected to the sewer from the individual sumps (SRS) because they were less concentrated than what was already in the spill tank.

The plot of the second case shows that the spill tank quickly reached its maximum level (L) and solids were pumped to the sewer (*) several times to make room for more concentrated spills. From the printout, 32,678 gallons were pumped to the sewer from the spill tank.

These four versions of the basic model illustrate some of the strategies that may be used to design a loss control system. A number of alternatives may be considered using various setpoints, pump capacities and collection tank sizes. Actual sewer data is used to simulate the system. The advantage of using conductivity times flow can be determined. Also, the simulation demonstrates the effect of selecting the position of the sump in terms of resulting tank volume and concentrations delivered to recovery.

Comparison of the results of the four models shows Model C to be the most effective. Table 6.6 summarizes the total amount of solids recovered and the final conductivity in the spill tank for each case.

6.14

TABLE 6.6 MODEL RESULT SUMMARY

Case/Model	Solids Recovered/Conductivity A	B	C	D
1	1143.2M/4425	1253.6M/2790	1117M/4867	1259.2M/2992
2	878.6M/3620	575.9M/2499	899.1M/6194	875.3M/2325

As can be seen, of the total solids potentially recoverable as represented by Case 1, Model C recovered the highest percentage in Case 2 and effectively concentrated the material in the spill tank as represented by the final conductivities. The concentrating effect can be noted on Figure 6.7 also.

These results would suggest, for the data used here, that pumping from the individual sumps using a conductivity setpoint and comparing the conductivity at the sump with that in the spill tank to make the final decision to pump to the spill tank when it is full would be the most effective strategy in the case of a limited spill tank volume.

In the case of unlimited availability of spill tankage, Model D, using mass setpoints to pump from the individual sumps, recovered the most amount of material and, therefore, allowed the least amount to go to the wastewater treatment plant. Model C, in this case, recovered the least but it was the most concentrated.

Time Series Analysis

Another technique useful for the characterization of process losses is a form of time series analysis called intervention analysis. The method described here was used both to demonstrate its application and to show its potential for control, as well as characterization, of process losses.

6.15

Process losses or spills are uncertain. They occur at random intervals, for random lengths of time and are of variable magnitude. Furthermore, they may not be recognized at the process level as quickly as they manifest themselves in the process sewer. For example, a small leak in a sulfuric acid holding tank may initially go unnoticed by an operator, but a conductivity sensor in the sewer draining the holding tank will quickly respond to the presence of excess hydrogen ion in the process wastewater.

The ability to describe as well as detect a process loss from the analysis of a record of a suitable wastewater parameter, such as flow times conductivity, could provide a useful means of loss control. The problem is that any such analysis method must be able to separate real process losses from the intermittent random variability of the process wastewater itself. Intervention analysis appears to be ideally suited to this task. The time series component of this method allows one to describe the stochastic nature of the wastewater variable. The interventions are used to describe the process losses.

The use of intervention analysis as applied here is more an inference application rather than a descriptive one. Box and Tiao (3) used intervention analysis to determine the effect on a response of a known intervention. In this application, however, the occurrence of a process loss is not known a priori. Instead, anomalies in the time series are assumed to be spills and their effects are estimated assuming they were known to have occurred. The effect of the process loss can then be removed from the record and a stochastic time series model fit to the loss corrected time series.

The procedure is described schematically in Figure 6.9. The process wastewater time series, (a), is envisioned as being the sum of two components.

6.16

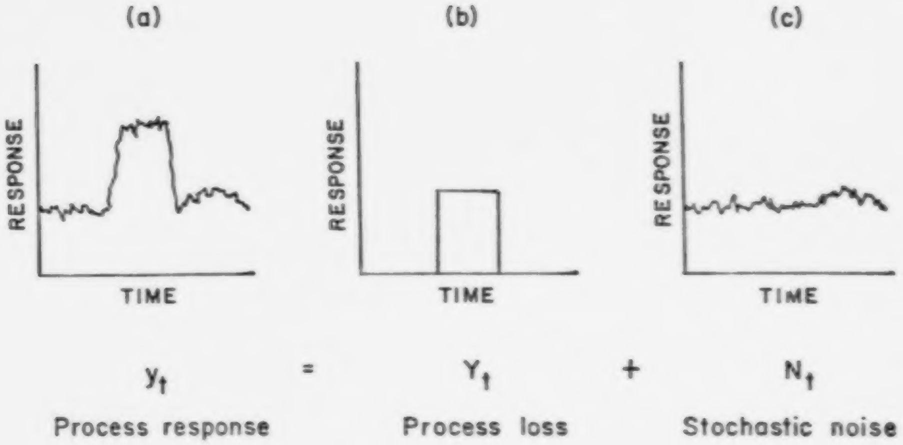

(a)
(b)
(c)
RESPONSE
TIME
RESPONSE
TIME
RESPONSE
TIME
y_t
=
Y_t
+
N_t
Process response
Process loss
Stochastic noise

Figure 6.9 Schematic Representation of Intervention Analysis

6-17

One is the process loss(es), (b), the other is the inherent stochastic variability, (c). In Figure 6.9, the process wastewater time series has random fluctuations of both high and low frequency. Also, about one-third of the way into the record, the magnitude of the response increases sharply, remains at an elevated value, and then falls back approximately to its original level. The record continues to exhibit its random fluctuation during this series of events. The sudden pulse observed in the record is the object of intervention analysis. The magnitude of the change that occurred during that time interval is not characteristic of the random fluctuations found elsewhere in the record. Therefore, it seems reasonable to assume that the pulse represents an intervention in the time series, in this case a process loss. The process loss in this example is characterized as a rectangular pulse. The area under the pulse is an estimate of the mass of material lost. Other shapes, such as spikes and increasing or decreasing exponentials, can be modeled.

The models used in intervention analysis are more fully discussed by Box and Tiao (3) and Box and Jenkins (2). Only the basic structure of these models will be presented here. As indicated in Figure 6.9, the observed response is modeled as the sum of two components; the intervention (process loss) and the stochastic noise:

$$y(t) = Y(t) + N(t) \qquad \text{(Eq. 1)}$$

where,

$y(t)$ = observed process wastewater response

$Y(t)$ = dynamic transfer function for the intervention

$N(t)$ = stochastic noise model

The noise component is usually represented as a mixed autoregressive moving average stochastic model as follows (2):

(Eq. 2) $\phi(B)N(t) = \theta\ (B)a(t)$

where,

$\phi(B)$ is the autoregressive operator, defined as a polynomial of order p, and equals $1 - \phi_1B-\phi_2B^2\ .\ .\ .\ .\ -\phi_pB^p$

$\theta(B)$ is the moving average operator, defined as a polynomial of order q, and equals $1 - \theta_1B-\theta_2B^2\ .\ .\ .\ .\ -\theta_qB^q$

B is the backshift operator, thus $By(t) = y(t-1)$

$N(t)$ is the noise component of the time series record

$a(t)$ is a sequence of independently distributed normal random variables with zero mean and constant variance (white noise)

Adjustments can be made to Equation 2 for seasonal nonstationarity in the data record. This is usually done by differencing (see Box and Jenkins (2)).

The intervention component of the model is assumed to have a form similar to that of Equation 2.

(Eq. 3) $\delta(B)Y(t) = w(B)e(t)$

where,

$\delta(B)$ and $w(B)$ are polynomials of order r and s respectively, which determine the exact nature of the intervention. Box and Tiao (3) describe a number of different responses (Figure B in reference 3)

$y(t)$ is the dynamic transfer function for the intervention

$e(t)$ is an indicator variable assuming a value of 0 or 1 to signify the occurrence or nonoccurrence of the intervention.

Thus, the general form of the intervention analysis model is as follows:

(Eq. 4) $y(t) = \frac{w(B)}{\delta(B)}\ e(t) + \frac{\theta(B)}{\phi(B)}\ a(t)$

6-19

The example chosen for intervention analysis is a 19 hour record of the product of wastewater flow and conductivity (gpm*μmho/cm). Each data point in the record is a 10 minute average value. The original time series is shown in Figure 6.10. The dominant features in the record are a large peak at about 2 to 3 hours and another less intense one at 14 to 15 hours. In addition, there are some smaller peaks; for example, at 6.5, 7.5, 8.5 and 18 hours, which could possibly be interpreted as process losses. For this analysis, however, only the two dominant peaks were assumed to be process loss interventions.

A number of assumptions were made in modeling this data record. Inspection of Figure 6.10 shows that there are order of magnitude changes in the response variable (flow x conductivity). Therefore, a logarithmic transformation of the data was used for analysis to improve the error structure. The logarithmic transformation is plotted in Figure 6.10. The interventions used to characterize the process losses were assumed to be rectangular pulses. This type of intervention is the simplest to model and should provide a reasonable description of the loss. It assumes that there is no lag or drag out associated with the loss and that the effect of the loss is constant and felt immediately in the process wastewater. This assumption about the shape of the interventions can be modified by using more complicated intervention transfer functions (3). The rectangular pulses used here demonstrate how well this simple approximation will work.

The interventions for the two dominant peaks in the record were modeled as follows. The first peak appears to have a high value with two shoulders of equal height on either side. Thus, two interventions (one for the central value and one for the shoulders) were used to describe it. The second peak

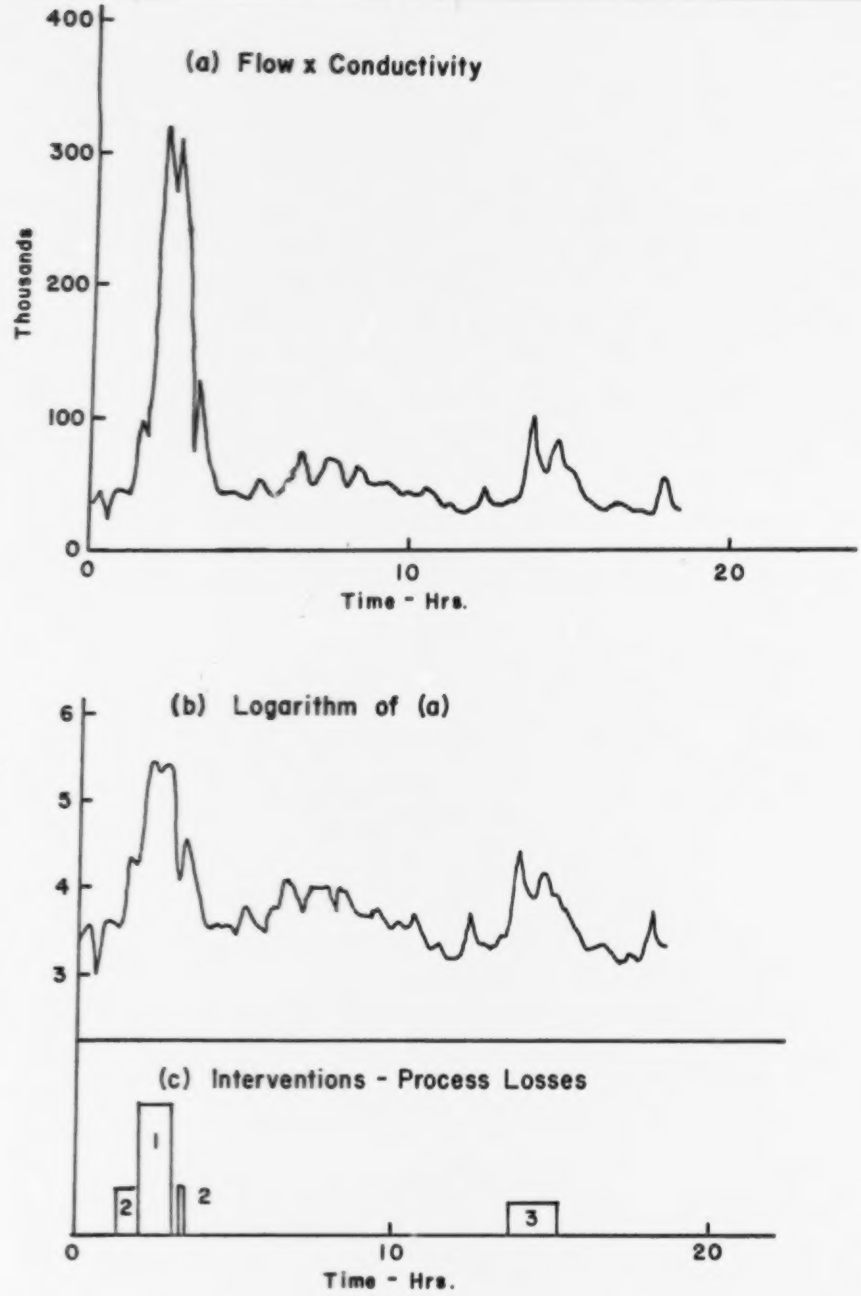


Figure 6.10 Intervention Analysis of Time Series

was modeled as a broad steady intervention of moderate height. The interventions and times they occur are shown graphically in Figure 6.10. The stochastic part of the model, N(t), was found to be adequately represented by an ARMA(1,1) model. Thus, the form of the time series model, with interventions, that was fit to the logarithmic transformation of the data was:

$$\text{(Eq. 5)} \qquad y(t) = \bar{y} + w(1)*e(1,t) + w(2)*e(2,t) + w(3)*e(3,t) + ((1-\theta B)/(1-\phi B))*a(t)$$

where,

$y(t)$ = natural log of flow x conductivity

$\bar{y}$ = mean of the record

$w(1)$, $w(2)$ and $w(3)$ are the effects of the first, second, and third interventions, respectively.

$e(1,t)$ is an indicator variable for the first intervention (central peak) and equals 1 during observations 13 to 18 and 0 elsewhere

$e(2,t)$ is an indicator variable for the second intervention shoulders and equals 1 during observations 9 to 12 and 20 to 21 and 0 elsewhere

$e(3,t)$ is an indicator variable for the third intervention (peak late in record) and equals 1 during observations 82 to 91 and 0 elsewhere

θ is the moving average parameter for the stochastic model

ϕ is the autoregressive parameter for the stochastic model

B is the backshift operator and

$a(t)$ are the random (white noise) inputs

The model, Equation 5, was fit to the data using an estimation package

6-22

for time series analysis with interventions obtained from the Academic Computing Center, University of Wisconsin, Madison. The least squares estimates of the parameters and their approximate 95% confidence intervals are given in Table 6.7. Inspection of these correlations among parameter estimates and the autocorrelations among the residuals show no lack of fit or adequacy in the model. The amount of material in these process losses can be estimated by determining the area under the intervention pulses. These computations are summarized in Table 6.8.

TABLE 6.7 LEAST SQUARES ESTIMATES AND APPROXIMATE 95% CONFIDENCE INTERVALS FOR PARAMETERS IN EQUATION 5

Parameter	Least Squares Estimate	Approximate 95% Confidence Interval	
$\bar{y}$	3.79	3.58	3.99
θ	0.40	0.16	0.64
ϕ	0.89	0.77	1.01
w(1)	1.54	1.25	1.83
w(2)	0.65	0.44	0.87
w(3)	0.52	0.27	0.77

Residual mean square = 0.0357
Residual standard error = 0.19
Note: This analysis is on the natural logarithm transformation of the original time series

TABLE 6.8 SUMMARY OF PROCESS LOSSES

Intervention	Width (min)	Height gpm*(μmho/cm)	Mass gal*(μmho/cm)
1	60	160 K	9600
2	60	40 K	2400
3	100	30 K	3000

Estimate of error - ±5%

Note: In these calculations, the information has been converted from logarithms to actual data units.

The use of the model for control of process losses can be demonstrated as follows. Because the stochastic portion of the model

$$\text{(Eq. 6)} \qquad y(t) = \bar{y} + ((1-\theta B)/(1-\phi B))*a(t)$$

represents the inherent level of the response variable, a comparison of a one step forecast (10 min. average) from Equation 6 with the actual observed response provides a measure of system status. If the observed and forecast values are within error limits, no control action is required. If the observed value is significantly higher than the forecast value, a loss condition potentially exists and control action should be taken. Once control action is initiated, it would continue until observed and forecast values agree within the error limits. The forecast model must be updated periodically to accommodate long term trends in process operation.

Intervention analysis has been shown to be applicable to the study and control of process losses. It can be used to estimate the magnitude of losses and to determine the stochastic nature of a process sewer response variable. The stochastic models obtained from this analysis can be used to forecast sewer response to provide a means of control action.

REFERENCES

1. Pugh III, A.L., Dynamo User's Manual, 5th ed., The MIT Press, Cambridge, Mass., 1977
2. Box, G.E.P. and Jenkins, G.M., Time Series Analysis, Forecasting and Control, 2nd ed., Holden-Day, San Francisco, California, 1977
3. Box, G.E.P. and Tiao, G.C., "Intervention Analysis with Applications to Economic and Environmental Problems," Journal of the American Statistical Association, 70, (349) 70, March, 1975

```
                                                               Case 1


 TIME        PM1      PMS      LST                            PTS      CNS
             PM2      PMR               ACS      STR
             PM3                        CST      STS          SPS      SRS
             PM4

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  E-00      E-00     E-00     E-00                           E-00     E-00
            E-00     E-00              E 06     E 06
            E-00                       E-00     E 06         E-00     E-00
            E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  0.00    150.00   200.00       1.                             0.   3603.7
            0.00     0.00              0.00     0.00
            0.00                        1.0     0.00           0.       0.
           50.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

100.00    221.74   521.74   22184.                             0.   2915.3
          219.67   270.00             70.54    81.92
            0.00                     3179.8     8.39           0.       0.
           80.33

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

200.00    249.96   402.88   46959.                             0.   6019.5
            0.00   270.00            154.07   172.52
            0.00                     3280.9    15.34           0.       0.
          152.92

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

300.00    217.55   441.29   62861.                             0.   4682.7
            0.00   270.00            268.82   281.09
            0.00                     4276.3    35.47           0.       0.
          223.74
```

Figure 6.5 Printout of Model A Results

```
400.00   144.16   393.99   78298.                            0.   3681.0
           0.00   270.00            344.25   400.27
           0.00                     4396.7    52.57          0.       0.
         249.83

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00    74.32   289.69   85754.                            0.   5082.2
           0.00   270.00            387.22   519.60
           0.00                     4515.5    74.42          0.       0.
         215.37

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


600.00     0.00   141.25   85059.                            0.   4705.6
           0.00   270.00            387.30   645.78
           0.00                     4553.3   107.55          0.       0.
         141.25

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99    86.87   372.45   74240.                            0.   2435.7
           0.00   270.00            339.49   769.35
         213.13                     4572.9   134.35          0.       0.
          72.45

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99   161.65   212.33   57443.                            0.   2206.6
           0.00   270.00            254.21   889.07
           0.00                     4425.4   167.92          0.       0.
          50.68
```

Figure 6.5 cont.

```
PM1=1,PM2=2,PM3=3,PM4=4

  0.000          62.500         125.000         187.500         250.000   1234
  0.02    - - - - 4  .  - - - - - -  .  - -1- - -    .  - - - - - -  . 23
     3            4  .               .         1     .               2
     3              4.               .              1.              2.
     3               4               .               . 1          2  .
     3               .4              .               .    1     2    .
     3               .   4           .               .       21      .
     3               .       4       .               .    2      1   .
     3               .          4    .               .2           1  .
     3               .              4.            2  .              1.
     3               .               .  4     2      .               1
200.02  - - - - - -  .  - - - - - -  .  - -4- - -    .   - - - - - - 1 23
     2               .               .         4     .               1 23
     2               .               .              4.              1. 23
     2               .               .               . 4          1  . 23
     2               .               .               .      4   1    . 23
     2               .               .               .       14      . 23
     2               .               .               .   1       4   . 23
     2               .               .               .1           4  . 23
     2               .               .            1  .              4. 23
     2               .               .        1      .               4 23
400.02  - - - - - -  .  - - - - - -  .  - 1 - - -    .   - - - - - - 4 23
     2               .               .1              .               4 23
     3              2.            1  .               .              4.
     2               .        1      .               .           4   . 23
     2               .    1          .               .          4    . 23
     2               .  1            .               .      4        . 23
     1               .               .               .   4           . 123
     1               .               .               4               . 123
     1               .               .           4   .              3. 12
     1               .               .       4       .               3 12
600.01  - - - - - -  .  - - - - - -  .  -4- - - -    .  - - - - - -  . 123
     2            1  .               4               .               . 23
     2              1.           4   .               .               . 23
     2               .1      4       .               .               . 23
     2               .  1 4          .               .               . 23
     2               .  4   1        .               .      3        .
     1               4               .               .               . 123
     1              4.               .               .               . 123
     1            4  .               .               .               . 123
     1            4  .               .               .               . 123
800.02    - - - - 4  .  - - - - - -  .   - - -1- -   .  - - - - - -  . 23
```

Figure 6.5 cont.

```
LST=L,ACS=C,CST=N,PTS=*

   0.000T       25.000T       50.000T       75.000T      100.000T L
   0.000M      100.000M      200.000M      300.000M      400.000M C
   0.000T        2.000T        4.000T        6.000T        8.000T N
  -2.000        -1.000         0.000         1.000         2.000  *
   0.0L - - - - - - . - - - - - - * - - - - - - . - - - - - - . LCN
      . L           .      N      *             .             . LC
      .  CL         .       N     *             .             .
      .     CL      .        N    *             .             .
      .       CL    .        N    *             .             .
      .        C   L.       N     *             .             .
      .            C.L       N    *             .             .
      .             . C L       N *             .             .
      .             .   C L   N   *             .             .
      .             .     C N L   *             .             .
 200.0. - - - - - - . - -  C N  -L* - - - - - - . - - - - - - .
      .             .            CL             .             . CN,L*
      .             .             NL            .             . LC,N*
      .             .             *N LC         .             .
      .             .             * N   LC      .             .
      .             .             * N    L  C   .             .
      .             .             * N       L  C.             .
      .             .             *   N      L  .C            .
      .             .             *   N        L.   C         .
      .             .             *   N         L    C        .
 400.0. - - - - - - . - - - - - - * N - - - - - .  L -C- - -  .
      .             .             * N           .   L  C      .
      .             .             *   N         .    L    C   .
      .             .             *   N         .    L     C  .
      .             .             *   N         .      L   C  .
      .             .             *   N         .      L    C .
      .             .             *    N        .      L     C.
      .             .             *     N       .    L        C
      .             .             *     N       .    L        C
      .             .             *    N        .     L       C
 600.0. - - - - - - . - - - - - - *  -N- - - -  .   - -L- - C .
      .             .             *   N         .     L    C  .
      .             .             *   N         .    L    C   .
      .             .             *   N         .   L    C    .
      .             .             *   N         .L      C     .
      .             .             *   N         L      C      .
      .             .             *   N        L.   C         .
      .             .             *  N       L  .C            .
      .             .             *  N     L   C.             .
      .             .             *    N L   C  .             .
 800.0. - - - - - - . - - - - - - *  -NL  -C- - . - - - - - - .
```

Figure 6.5 cont.

```
                              CHANGES FOR RERUN -       Case 2
ORIGINAL LTOP       1.000M
 PRESENT LTOP      10.000T

  TIME        PM1     PMS     LST                         PTS      CNS
              PM2     PMR             ACS      STR
              PM3                     CST      STS        SPS      SRS
              PM4

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   E-00      E-00    E-00    E-00                        E-00     E-00
             E-00    E-00            E 03     E 06
             E-00                    E-00     E 06       E 03     E 03
             E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   0.00    150.00  200.00      1.                        0.00   3603.7
             0.00    0.00              0.     0.00
             0.00                     1.0     0.00         0.       0.
            50.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 100.00    221.74  521.74   9997.                        0.00      0.0
           219.67  270.00          32824.    92.89
             0.00                  3283.5    44.48       992.    3155.
            80.33

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 200.00    249.96  249.96  10004.                      249.96   6019.5
             0.00  270.00          36195.   193.61
             0.00                  3617.9   121.65     13352.   15670.
             0.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 300.00      0.00    0.00  10014.                        0.00   4682.7
             0.00  270.00          49928.   329.34
             0.00                  4986.0   210.22     31390.   30882.
           223.74
                                                                 - - -
```

Figure 6.5 cont.

```
400.00   144.16   393.99    9974.                                0.00     0.0
           0.00   270.00             43941.   467.08
           0.00                      4405.7   288.83   37064.   59767.
         249.83

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00    74.32   289.69    9981.                                0.00  5082.2
           0.00   270.00             50247.   592.42
           0.00                      5034.1   339.21   47530.   68317.
         215.37

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


600.00     0.00   141.25    8065.                                0.00  4705.6
           0.00   270.00             32817.   736.01
           0.00                      4068.8   373.99   47530.   69346.
         141.25

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99    86.87   372.45    1107.                                0.00  2435.7
           0.00   270.00              4531.   840.06
         213.13                      4092.6   400.78   47530.   69346.
          72.45

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99   161.65   212.33     997.                                0.00  2206.6
           0.00     0.00              3608.   875.42
           0.00                      3620.1   434.35   47530.   69346.
          50.68
```

Figure 6.5 cont.

```
PM1=1,PM2=2,PM3=3,PM4=4

 0.000       62.500     125.000     187.500     250.000  1234
  0.02 - - - - 4 . - - - - - . - -1- - - . - - - - - . 23
     3         4 .           .       1   .           2
     3          4.           .          1.          2.
     3           4           .           . 1       2 .
     3           .4          .           .   1   2   .
     3           .  4        .           .     21    .
     2           .           .           .        1  . 234
     3           .       4   .           .2        1 .
     1           .          4.           .           . 123
     3           .           . 4    2    .           1
200.02 - - - - - . - - - - - . - - - - - . - - - - - 1 234
     2           .           .       4   .           1 23
     2           .           .          4.          1. 23
     2           .           .           . 4       1 . 23
     2           .           .           .    4  1   . 23
     1           .           .           .      4    . 123
     2           .           .           .  1     4  . 23
     2           .           .           .1        4 . 23
     2           .           .         1 .          4. 23
     2           .           .      1    .           4 23
400.02 - - - - - . - - - - - . - 1 - - - . - - - - - 4 23
     1           .           .           .           4 123
     3          2.         1 .           .          4.
     2           .      1    .           .        4  . 23
     2           .   1       .           .       4   . 23
     2           . 1         .           .    4      . 23
     1           .           .           .  4        . 123
     1           .           .           4           . 123
     1           .           .        4  .          3. 12
     1           .           .     4     .           3 12
600.01 - - - - - . - - - - - . -4- - - - . - - - - - . 123
     2         1 .           4           .           . 23
     2          1.        4  .           .           . 23
     2           .1    4     .           .           . 23
     2           . 1 4       .           .           . 23
     2           . 4  1      .           .    3      .
     1           4           .           .           . 123
     1          4.           .           .           . 123
     1         4 .           .           .           . 123
     1         4 .           .           .           . 123
800.02 - - - - 4 . - - - - - . - - -1- - . - - - - - . 23
```

Figure 6.5 cont.

```
 LST=L,ACS=C,CST=N,PTS=*


  0.000T      2.500T      5.000T      7.500T     10.000T L
  0.000M     20.000M     40.000M     60.000M     80.000M C
  0.000T      2.000T      4.000T      6.000T      8.000T N
  0.000     100.000     200.000     300.000     400.000  *
  0.0L - - - - - . - - - - - . - - - - - . - - - - - . LCN*
     *       C   .     N L   .           .           .
     *           .  C   N    .           .  L        .
     *           .           . C         .           L CN
     *           .           C           .           L CN
     *           .       C   .           .           L CN
     .           .          C.   *       .           L CN
     *           .           .      C    .           L CN
     *           .       C   .           .           L CN
     *           .      C    .           .           L CN
200.0. - - - - - . - - - - C . - - * - - . - - - - - L CN
     *           .           .          C.           L CN
     *           .           .    C      .           L CN
     *           .           .      C    .           L CN
     *           .           .     C     .           L CN
     *           .           .     C     .           L CN
     *           .           .        C  .           L CN
     *           .           .       C   .           L CN
     *           .           .     C     .           L CN
     *           .           .     C     .           L CN
400.0* - - - - - . - - - - - . C - - - - . - - - - - L CN
     *           .           . C         .           L CN
     *           .           .     C     .           L CN
     *           .           .    C      .           L CN
     *           .           .  C        .           L CN
     *           .           .     C     .           L CN
     *           .           .      C   N.     L     .
     *           .           .   C      L. N         .
     *           .           . C       N .L          .
     *           .           C           .           L CN
600.0* - - - - - . - - - C - N - - - - - . -L- - - - .
     *           .  C        .  L        .           . LN
     *         C .    L      .  N        .           .
     *   C  L    .           .   N       .           .
     *  C L      .           .   N       .           .
     *  C L      .           .N          .           .
     *     C     . N     L   .           .           .
     *  C     L  .    N      .           .           .
     * C  L      .           N           .           .
     *  C L      .           .    N      .           .
800.0* C -L- - - . - - - - N . - - - - - . - - - - - .
```

Figure 6.5 cont.

Case 1

```
TIME        FL1     PM5     LST                         FPS      CN5
            FL2     PMR             ACS       STR
            FL3                     CST       STS       SPS      SRS
            FL4

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 E-00       E-00    E-00    E 03                        E-00     E-00
            E-00    E-00            E 06      E 06
            E-00                    E-00      E 03      E-00     E-00
            E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 0.00     150.00  600.00    0.00                          0.   1518.3
          250.00    0.00            0.00      0.00
          150.00                     1.0        0.        0.       0.
           50.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

100.00    221.74  600.00   45.53                          0.   2643.5
          219.67  270.00          122.68     38.43
           78.26                  2694.6        0.        0.       0.
           80.33

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

200.00    249.96  600.00   78.53                          0.   4420.7
          147.08  270.00          226.01    116.54
           50.04                  2878.1        0.        0.       0.
          152.92

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

300.00    217.55  600.00  111.53                          0.   3825.9
           76.26  270.00          381.57    204.95
           82.45                  3421.2        0.        0.       0.
          223.74
```

Figure 6.6 Printout of Model B Results

```
400.00  144.16  600.00  144.53                          0.  2747.0
         50.17  270.00          499.41  299.29
        155.84                  3455.4      0.          0.      0.
        249.83

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00   74.32  600.00  177.53                          0.  2844.1
         84.63  270.00          592.49  390.85
        225.68                  3337.4     -0.          0.      0.
        215.37

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


600.00   50.38  600.00  210.53                          0.  1813.8
        158.75  270.00          663.69  479.44
        249.62                  3152.5     -0.          0.      0.
        141.25

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99   86.87  600.00  243.53                          0.  1644.4
        227.55  270.00          686.13  559.95
        213.13                  2817.4     -0.          0.      0.
         72.45

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99  161.65    0.00  221.57                          0.  1042.7
        249.32  270.00          618.27  635.32
        138.35                  2790.4  60871.          0.      0.
         50.68

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Figure 6.6 cont.

TYPING GUIDE SHEET

```
 LST=L,ACS=C,CST=N,PM5=P,PTS=*,PMR=R

  0.000T     100.000T    200.000T    300.000T    400.000T L
  0.000M     200.000M    400.000M    600.000M    800.000M C
  0.000T       1.000T      2.000T      3.000T      4.000T N
  0.000      200.000     400.000     600.000     800.000  P
 -2.000      -1.000       0.000       1.000       2.000  *
  0.000      100.000     200.000     300.000     400.000  R
  0.0L - - - - - . - - - - - * - - - - - P - - - - - . LCNR
     RLC         .           *  N        P           .
     R  LC       .           *    N      P           .
     .   LC      .           *       N   P           . NR
     .    LC     .           *       N   P           . NR
     .    L C    .           *       N   P           . NR
     .     L  C  .           *       R N P           .
     .      L   C.           *       R   PN          .
     .       L   C           *       R   N           . NP
     .        L  C           *       R  NP           .
200.0. - - - -L- . C - - - - * - - - R -NP - - - - - .
     .         L .   C       *       R   P N         .
     .          L.     C     *       R   P  N        .
     .           L       C   *       R   P   N       .
     .           .L       C  *       R   P    N      .
     .           .L         C*       R   P    N      .
     .           . L         *C      R   P     N     .
     .           .  L        * C     R   P     N     .
     .           .   L       *   C   R   P     N     .
     .           .    L      *    C  R   P     N     .
400.0. - - - - - . - -L- - - * - - C R - P - -N- - - .
     .           .     L     *      CR   P    N      .
     .           .      L    *       C   P    N      . CR
     .           .       L   *       R C P    N      .
     .           .        L  *       R C P   N       .
     .           .        L  *       R   C   N       . CP
     .           .         L *       R   PC  N       .
     .           .          L*       R   P C N       .
     .           .           L       R   P  CN       . L*
     .           .           L       R   P  NC       . L*
600.0. - - - - - . - - - - - *L- - - R - P N C - - - .
     .           .           * L     R   PN  C       .
     .           .           *  L    R   N   C       . NP
     .           .           *   L   R  NP    C      .
     .           .           *   L   R  NP    C      .
     .           .           *    L  R N P    C      .
     P           .           *    L  RN  .    C      .
     P           .           *    L  RN  .   C       .
     P           .           *   L   RN  .  C        .
     P           .           *  L    RN  . C         .
800.0P - - - - - . - - - - - * -L- - RN- .C- - - - - .
```

Figure 6.6 cont.

6.35

```
                              CHANGES FOR RERUN -        Case 2

ORIGINAL LTOP      1.000M
 PRESENT LTOP     20.000T

 TIME        FL1      PM5      LST                           FPS       CN5
             FL2      PMR               ACS       STR
             FL3                        CST       STS        SPS       SRS
             FL4

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  E-00       E-00     E-00     E-00                          E-00      E-00
             E-00     E-00             E 03      E 06
             E-00                      E-00      E 06        E 06      E 06
             E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  0.00     150.00   600.00       1.                            0.    1518.3
           250.00     0.00               0.      0.00
           150.00                       1.0      0.00        0.00      0.00
            50.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

100.00     221.74     0.00   20011.                        16920.    2643.5
           219.67   270.00           54973.     40.27
            78.26                    2747.1     65.87       43.68     48.50
            80.33

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

200.00     249.96   600.00   20011.                        30780.    4420.7
           147.08   270.00           61803.    124.37
            50.04                    3088.5    156.38       85.62     99.71
           152.92

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

300.00     217.55     0.00   20011.                        44640.    3825.9
            76.26   270.00           78420.    230.82
            82.45                    3918.8    277.27      138.59    165.97
           223.74
```

Figure 6.6 cont.

```
400.00   144.16    0.00   20011.                     49860.   2747.0
          50.17  270.00           71392.   336.03
         155.84                   3567.7   391.27   159.52    189.61
         249.83

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00    74.32    0.00   20011.                     59340.   2844.1
          84.63  270.00           65074.   427.44
         225.68                   3251.9   490.82   191.48    223.57
         215.37

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

600.00    50.38    0.00   20011.                     65340.   1813.8
         158.75  270.00           53606.   511.19
         249.62                   2678.8   578.33   210.70    243.18
         141.25

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99    86.87    0.00   20014.                     65340.   1644.4
         227.55    0.00           50009.   525.91
         213.13                   2498.7   670.15   210.70    243.18
          72.45

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99   161.65    0.00   20014.                     65340.   1042.7
         249.32    0.00           50009.   525.91
         138.35                   2498.7   738.54   210.70    243.18
          50.68
```

Figure 6.6 cont.

6.27

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

```
LST=L,ACS=C,CST=N,PM5=P,PTS=*,PMR=R


  0.000T      5.000T     10.000T     15.000T     20.000T L
  0.000M     25.000M     50.000M     75.000M    100.000M C
  0.000T      2.000T      4.000T      6.000T      8.000T N
  0.000     200.000     400.000     600.000     800.000 P*
  0.000     100.000     200.000     300.000     400.000  R
  0.0L - - - - - . - - - - - . - - - - - P - - - - - . LCN*R
     *           .CN         .    L      P           . *R
     R           .  N        C           P           L P*
     .           .   N       . C     R   P           L P*
     P           .    N      . C     R   .           L P*
     P           .   N       . C     R   .           L P*
     .           .     N     .    C  R   P           L P*
     P           .        N  .       RC  .           L P*
     P           .       N   .      CR   .           L P*
     P           .     N     .    C  R   .           L P*
200.0. - - - - - . - - -N- - . - - C R - P - - - - - L P*
     .           .           N       R   P  C        L P*
     P           .           N       R   . C         L P*
     .           .           .N      R   P   C       L P*
     P           .           N       R   .  C        L P*
     P           .           N       R   . C         L P*
     .           .           N       R   P C         L P*
     P           .           N       R   .  C        L P*
     P           .          N.       R   .C          L P*
     P           .          N.       R   C           L P*
400.0P - - - - - . - - - -N- . - - - R C . - - - - - L P*
     P           .       N   .       RC  .           L P*
     .           .        N  .       RC  P           L P*
     P           .        N  .       RC  .           L P*
     P           .      N    .      CR   .           L P*
     P           .       N   .      CR   .           L P*
     P           .      N    .      CR   .           L P*
     P           .      N    .     C R   .           L P*
     P           .      N    .      CR   .           L P*
     P           .     N     .   C   R   .           L P*
600.0P - - - - - . - N - - - . C - - R - . - - - - - L P*
     P           .  N        C       R   .           L P*
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
     P           .  N        C           .           L P*R
800.0P - - - - - . -N- - - - C - - - - - . - - - - - L P*R
```

Figure 6.6 cont.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

6 38

Case 1

```
TIME       PM1     PMS     LST                           PTS      CNS
           PM2     PMR              ACS      STR
           PM3                      CST      STS         SPS      SRS
           PM4

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 E-00     E-00    E-00    E-00                          E-00     E-00
          E-00    E-00             E 06     E 06
          E-00                     E-00     E 06        E-00     E-00
          E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 0.00   150.00  200.00      1.                            0.   3603.7
          0.00    0.00             0.00     0.00
          0.                        1.0     0.00          0.       0.
         50.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

100.00  220.85  300.28  13416.                            0.   3066.7
          0.00  270.00            45.13    83.47
          0.                     3363.5    20.83          0.       0.
         79.43

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

200.00  250.00  400.40  21723.                            0.   6039.4
          0.00  270.00            82.63   188.32
          0.                     3803.8    48.68          0.       0.
        150.40

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

300.00  220.28  441.42  37478.                            0.   4667.1
          0.00  270.00           178.22   315.94
          0.                     4755.3    69.02          0.       0.
        221.13
```

Figure 6.7 Printout of Model C Results

```
400.00   149.20  449.20  55979.                             0.   3527.7
          50.00  270.00           252.35  443.86
             0.                   4507.8   82.69            0.       0.
         250.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00    78.59  298.59  66989.                             0.   5062.2
           0.00  270.00           304.90  564.14
             0.                   4551.4   98.94            0.       0.
         220.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

600.00    50.01  198.81  62902.                             0.   4355.9
           0.00  270.00           309.49  695.02
             0.                   4920.2  127.33            0.       0.
         148.80

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99    80.28  158.59  53106.                             0.   4380.9
           0.00  270.00           258.00  827.19
             0.                   4858.2  151.37            0.       0.
          78.31

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99     0.00   50.01  32882.                             0.   4696.7
           0.00  270.00           160.03  957.16
             0.                   4866.8  188.25            0.       0.
          50.01
```

Figure 6.7 cont.

```
 PM1=1,PM2=2,PM3=3,PM4=4

  0.000      62.500     125.000     187.500     250.000  1234
  0.02 - - - - 4 . - - - - - . - -1- - - . - - - - - . 23
     3         4 .           .       1   .           2
     3          4.           .          1.          2.
     3           4           .           . 1       2 .
     2           .4          .           .   1       . 23
     2           .  4        .           .     1     . 23
     2           .     4     .           .       1   . 23
     2           .       4   .           .         1 . 23
     2           .          4.           .          1. 23
     2           .           . 4         .           1 23
200.02 - - - - - . - - - - - . - -4- - - . - - - - - 1 23
     2           .           .       4   .           1 23
     2           .           .          4.          1. 23
     2           .           .           . 4       1 . 23
     2           .           .           .   4   1   . 23
     2           .           .           .     1     . 23,14
     2           .           .           .   1   4   . 23
     2           .           .           .1        4 . 23
     3         2 .           .          1.          4.
     3         2 .           .       1   .           4
400.03 - - - - 2 . - - - - - . - -1- - - . - - - - - 4
     3         2 .           . 1         .           4
     3          2.          1.           .          4.
     2           .       1   .           .         4 . 23
     2           .    1      .           .       4   . 23
     2           .  1        .           .     4     . 23
     1           .           .           .   4       . 123
     2           1           .           .4          . 23
     2         1 .           .          4.           . 23
     2         1 .           .       4   .           . 23
600.02 - - - - 1 . - - - - - . - -4- - - . - - - - - . 23
     2         1 .           . 4         .           . 23
     2          1.          4.           .           . 23
     2           1       4   .           .           . 23
     2           .1   4      .           .           . 23
     2           .  1        .           .           . 23,14
     1           .4          .           .           . 123
     1           4           .           .           . 123
     1         4 .           .           .           . 123
     1         4 .           .           .           . 123
800.01 - - - - 4 . - - - - - . - - - - - . - - - - - . 123
```

Figure 6.7 cont.

```
 LST=L,ACS=C,CST=N,PTS=*

  0.000T     20.000T     40.000T     60.000T     80.000T L
  0.000M    100.000M    200.000M    300.000M    400.000M C
  0.000T      2.000T      4.000T      6.000T      8.000T N
 -2.000      -1.000       0.000       1.000       2.000  *
  0.0L - - - - - . - - - - - * - - - - - . - - - - - . LCN
     .CL         .      N    *           .           .
     .  C L      .      N    *           .           .
     .    C L    .       N   *           .           .
     .    C  L   .       N   *           .           .
     .    C  L   .       N   *           .           .
     .     C  L  .         N *           .           .
     .       CL  .           * N         .           .
     .        CL .           *N          .           .
     .        C  L          N*           .           .
200.0. - - - - C .L- - - - -N* - - - - - . - - - - - .
     .           . CL        *   N       .           .
     .           .   L       *    N      .           . LC
     .           .     L     *     N     .           . LC
     .           .       L   *    N      .           . LC
     .           .        CL *    N      .           .
     .           .           CL   N      .           . C*
     .           .           * CL N      .           .
     .           .           *  CNL      .           .
     .           .           *   NC L    .           .
400.0. - - - - - . - - - - - * -N- C - L . - - - - - .
     .           .           * N    C    L           .
     .           .           *  N     C  . L         .
     .           .           *  N       C.  L        .
     .           .           *  N       C.   L       .
     .           .           *  N        .C  L       .
     .           .           *   N       . C L       .
     .           .           *    N      . CL        .
     .           .           *     N     .  L        . LC
     .           .           *     N     . L         . LC
600.0. - - - - - . - - - - - * - - N - - .CL - - - - .
     .           .           *     N     CL          .
     .           .           *    N     CL           .
     .           .           *    N    L .           . LC
     .           .           *    N  CL  .           .
     .           .           *    N CL   .           .
     .           .           *    CL     .           . CN
     .           .           * C LN      .           .
     .           .           CL   N      .           . C*
     .           .        CL *    N      .           .
800.0. - - - - - . - - -CL - * - -N- - - . - - - - - .
```

Figure 6.7 cont.

```
                                        CHANGES FOR RERUN -    Case 2

ORIGINAL LTOP      1.000M
 PRESENT LTOP     10.000T

  TIME        PM1     PMS     LST                        PTS      CNS
              PM2     PMR               ACS      STR
              PM3                       CST      STS     SPS      SRS
              PM4

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  E-00       E-00    E-00    E-00                       E-00     E-00
             E-00    E-00              E 03     E 06
             E-00                      E-00     E 06    E 03     E 06
             E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  0.00     150.00  200.00      1.                       0.00   3603.7
             0.00    0.00                0.     0.00
               0.                       1.0     0.00      0.     0.00
            50.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

100.00       0.00    0.00  10000.                       0.00   3066.7
             0.00  270.00            34151.    84.55
               0.                    3415.0    30.73    972.    10.03
             0.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

200.00     250.00  250.00  10012.                     250.00   6039.4
             0.00  270.00            39798.   193.32
               0.                    3974.9   [illegible]52   9552.    36.07
             0.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

300.00     220.28  441.42   9999.                       0.00   4667.1
             0.00  270.00            49972.   336.86
               0.                    4997.6   176.34  33658.    89.87
           221.13
```

Figure 6.7 cont.

```
 400.00     0.00     0.00  10009.                             0.00   3527.7
            0.00   270.00            44842.   474.28
              0.                     4480.1   259.77  59532.   140.77
            0.00

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 500.00     0.00   220.00  10000.                             0.00   5062.2
            0.00   270.00            51442.   600.78
              0.                     5144.0   315.76  81002.   163.82
          220.00

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


 600.00    50.01   198.81   5684.                             0.00   4355.9
            0.00   270.00            28179.   758.53
              0.                     4957.7   345.13  81791.   164.24
          148.80

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 699.99    80.28   158.59    991.                             0.00   4380.9
            0.00     0.00             4513.   862.88
              0.                     4554.2   369.18  81791.   164.24
           78.31

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 799.99     0.00    50.01    990.                             0.00   4696.7
            0.00     0.00             6131.   893.26
              0.                     6193.6   406.05  81791.   164.24
           50.01
```

Figure 6.7 cont.

```
PM1=1,PM2=2,PM3=3,PM4=4

 0.000      62.500       125.000       187.500       250.000  1234
  0.02 - - - - 4 . - - - - - - . - -1- - -   . - - - - - - . 23
     3         4 .             .        1    .             2
     3          4.             .            1.            2.
     3           4             .             . 1         2 .
     2           .4            .             .    1        . 23
     1           .             .             .             . 1234
     2           .      4      .             .         1   . 23
     2           .             .             .           1 . 234
     1           .             .             .             . 1234
     2           .             . 4           .             1 23
200.02 - - - - - . - - - - - - . - - - - - - . - - - - - - 1 234
     2           .             .         4   .             1 23
     2           .             .            4.            1. 23
     2           .             .             .           1 . 234
     1           .             .             .    4        . 123
     2           .             .             .      1      . 23,14
     2           .             .             .    1    4   . 23
     1           .             .             .             . 1234
     1           .             .             .            4. 123
     1           .             .             .             4 123
400.01 - - - - - . - - - - - - . - - - - - - . - - - - - - . 1234
     3         2 .             . 1           .             4
     3          2.            1.             .            4.
     2           .        1    .             .           4 . 23
     2           .     1       .             .         4   . 23
     1           .             .             .      4      . 123
     1           .             .             .    4        . 123
     2           1             .             .4            . 23
     2         1 .             .            4.             . 23
     2         1 .             .         4   .             . 23
600.02 - - - - 1 . - - - - - - . - -4- - -   . - - - - - - . 23
     2         1 .             . 4           .             . 23
     2          1.            4.             .             . 23
     2           1        4    .             .             . 23
     2           .1    4       .             .             . 23
     2           .  1          .             .             . 23,14
     1           .4            .             .             . 123
     1           4             .             .             . 123
     1         4 .             .             .             . 123
     1         4 .             .             .             . 123
800.01 - - - - 4 . - - - - - - . - - - - - - . - - - - - - . 123
```

Figure 6.7 cont.

```
  LST=L,ACS=C,CST=N,PTS=*

   0.000T      2.500T      5.000T      7.500T     10.000T L
   0.000M     20.000M     40.000M     60.000M     80.000M C
   0.000T      2.000T      4.000T      6.000T      8.000T N
   0.000     100.000     200.000     300.000     400.000   *
    0.0L - - - - - . - - - - - . - - - - - . - - - - - . LCN*
      *     C     .    L N    .           .           .
      *           . C    N    .           L           .
      *           .        C  .           .           L CN
      *           .        C  .           .           L CN
      *           .       C   .           .           L CN
      *           .          C.           .           L CN
      .           .           .   C*      .           L CN
      *           .           . C         .           L CN
      *           .          C.           .           L CN
 200.0. - - - - - . - - - - - C - - * - - . - - - - - L CN
      *           .           .          C.           L CN
      *           .           .        C  .           L CN
      .           .           .    *   C  .           L CN
      .           .           .*     C    .           L CN
      *           .           .     C     .           L CN
      *           .           .       C   .           L CN
      *           .           .        C  .           L CN
      .           .           .    *C     .           L CN
      *           .           .    C      .           L CN
 400.0* - - - - - . - - - - - . -C- - - - . - - - - - L CN
      *           .           . C         .           L CN
      *           .           .    C      .           L CN
      *           .           .    C      .           L CN
      *           .           .   C       .           L CN
      *           .           .      C    .           L CN
      *           .           .        C N.        L  .
      *           .           .      C    .N  L       .
      *           .           .      C    . LN        .
      *           .           C        LN .           .
 600.0* - - - - - . - -C- - - . -L- N - - . - - - - - .
      *           C       L   .     N     .           .
      *     C    L.           .   N       .           .
      *  C L      .           .   N       .           .
      *  C L      .           .   N       .           .
      *  C L      .           .  N        .           .
      * C  L      .           N           .           .
      * C  L      .           .N          .           .
      *  C L      .           . N         .           .
      *  C L      .           .     N     .           .
 800.0* - CL- - - . - - - - - . - - - - - .N- - - - - .
```

Figure 6.7 cont.

Case 1

```
 TIME      PM1     PMS     LST                       PTS     CNS
           PM2     PMR             ACS      STR
           PM3                     CST      STS      FPS     SRS
           PM4                                       SPS

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  E-00    E-00    E-00    E 03                      E-00    E-00
          E-00    E-00            E 06     E 06
          E-00                    E-00     E 03     E-00    E-00
          E-00                                      E-00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  0.00  150.00  350.00    0.00                        0.  2395.3
          0.00    0.00            0.00     0.00
        150.00                     1.0       0.       0.      0.
         50.00                                        0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

100.00  221.74  521.74   26.57                        0.  2915.3
        219.67  270.00           83.31    71.56
          0.00                  3135.4    6247.       0.      0.
         80.33                                        0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

200.00  249.96  549.96   53.64                        0.  4744.3
        147.08  270.00          171.15   161.09
          0.00                  3190.6   10314.       0.      0.
        152.92                                        0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

300.00  217.55  517.55   80.32                        0.  4284.9
         76.26  270.00          309.04   260.60
          0.00                  3847.9   16873.       0.      0.
        223.74                                        0.
```

Figure 6.8 Printout of Model D Results

647

```
- - -

400.00   144.16   549.83   102.06                                 0.   2879.4
           0.00   270.00             402.50   368.43
         155.84                      3943.8   27766.          0.       0.
         249.83                                               0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00    74.32   515.37   130.68                                 0.   3166.7
           0.00   270.00             479.97   470.63
         225.68                      3673.0   32735.          0.       0.
         215.37                                               0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


600.00    50.38   441.25   151.67                                 0.   2317.5
           0.00   270.00             535.27   568.89
         249.62                      3529.1   38972.          0.       0.
         141.25                                               0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99    86.87   372.45   165.12                                 0.   2435.7
           0.00   270.00             538.76   660.36
         213.13                      3262.9   46950.          0.       0.
          72.45                                               0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99   161.65   212.33   172.01                                 0.   2206.6
           0.00   270.00             514.80   744.43
           0.00                      2992.9   55230.          0.       0.
          50.68                                               0.
```

Figure 6.8 cont.

```
PM1=1,PM2=2,PM3=3,PM4=4

 0.000      62.500     125.000     187.500     250.000  1234
  0.02 - - - - 4 . - - - - - . - -1- - - . - - - - - . 13
     3         4 .           .       1   .           2
     3          4.           .          1.          2.
     3           4           .           . 1       2 .
     3           .4          .           .   1   2   .
     3           .  4        .           .    21     .
     3           .     4     .           .   2    1  .
     3           .       4   .           .2        1 .

3        .          4.         2 .          1.
     3           .           . 4    2    .           1
200.03 - - - - - . - - - - - . - 24- - - . - - - - - 1
     3           .           .2      4   .
             1
     3           .         2 .          4.          1.
     3           .      2    .           . 4       1 .
     3           .    2      .           .    4  1   .
     3           .  2        .           .     14    .
     2           .           .           .  1      4  . 23
     2           .           .           .1        4 . 23
     2           .           3         1 .          4.
     2           .           .  3   1    .           4
400.02 - - - - - . - - - - - . - 1 3 - - . - - - - - 4
     2           .           .1       3  .           4
     .          2.         1 .           3          4.
     .           2      1    .           .  3      4  .
     2           .   1       .           .    3  4   .
     2           . 1         .           .    4 3    .
     2           1           .           .  4      3  .
     2          1.           .           4          3.
     2         1 .           .        4  .          3.
     2         1 .           .     4     .           3
600.02 - - - - 1 . - - - - - . -4- - - . - - - - - 3
     2         1 .           4           .          3.
     2          1.        4  .           .         3 .
     2           .1    4     .           .        3  .
     2           . 1 4       .           .      3    .
     2           . 4  1      .           .    3      .
     2           4      1    .           . 3         .
     2          4.         1 .           3           .
     2         4 .           .1       3  .           .
     2         4 .           .   1 3     .           .
800.02 - - - - 4 . - - - - - . - - -1- - . - - - - - . 23
```

Figure 6.8 cont.

```
LST=L,ACS=C,CST=N,PTS=*

  0.000T     50.000T    100.000T    150.000T    200.000T L
  0.000M    200.000M    400.000M    600.000M    800.000M C
  0.000T      2.000T      4.000T      6.000T      8.000T N
 -2.000      -1.000      0.000       1.000       2.000  *
  0.0L - - - - - . - - - - - * - - - - - . - - - - - . LCN
     .CL         . N         *           .           .
     . CL        .    N      *           .           .
     .  CL       .      N    *           .           .
     .   CL      .      N    *           .           .
     .    CL     .      N    *           .           .
     .     C L   .       N   *           .           .
     .       CL  .        N  *           .           .
     .        CL .       N   *           .           .
     .        C  L      N    *           .           .
200.0. - - - - C .L- - -N- - * - - - - - . - - - - - .
     .           .CL       N *           .           .
     .           . C L     N *           .           .
     .           .    CL    N*           .           .
     .           .     CL   N*           .           .
     .           .      L   N*           .           . LC
     .           .       L   N           .           . LC,N*
     .           .        L  N           .           . LC,N*
     .           .         L N           .           . LC,N*
     .           .          LN           .           . LC,N*
400.0. - - - - - . - - - - - L - - - - - . - - - - - . LCN*
     .           .          N*CL         .           .
     .           .          N* CL        .           .
     .           .          N*  C L      .           .
     .           .         N *   C L     .           .
     .           .         N *    C L    .           .
     .           .         N *     C  L  .           .
     .           .         N *      C  L .           .
     .           .         N *       C  L.           .
     .           .         N *       C   L           .
600.0. - - - - - . - - - -N- * - - - C - L - - - - - .
     .           .        N  *       C   .L          .
     .           .       N   *       C   . L         .
     .           .       N   *       C   .  L        .
     .           .       N   *       C   .  L        .
     .           .       N   *       C   .   L       .
     .           .      N    *       C   .   L       .
     .           .      N    *       C   .    L      .
     .           .     N     *      C    .    L      .
     .           .     N     *      C    .    L      .
800.0. - - - - - . - - N - - * - - -C- - . - -L- - - .
```

Figure 6.8 cont.

```
                                 CHANGES FOR RERUN -    Case 2

ORIGINAL LTOP       1.000M
 PRESENT LTOP      20.000T

  TIME         PM1      PMS      LST                         PTS      CNS
               PM2      PMR             ACS      STR
               PM3                      CST      STS         FPS      SRS
               PM4                                           SPS

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   E-00       E-00     E-00     E-00                        E-00     E-00
              E-00     E-00            E 06     E 06
              E-00                     E-00     E 06        E-00     E 06
              E-00                                          E 06

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   0.00     150.00   350.00       1.                        0.00   2395.3
              0.00     0.00            0.00     0.00
            150.00                      1.0     0.00          0.     0.00
             50.00                                          0.00

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 100.00     221.74   221.74   20006.                      221.74   3260.3
              0.00   270.00           64.04    71.84
              0.00                   3201.0    25.23        412.    18.55
              0.00                                          1.32

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 200.00     249.96   249.96   20011.                      249.96   4744.3
              0.00   270.00           70.85   168.98
              0.00                   3540.5   102.72       6211.    73.60
              0.00                                         21.89

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 300.00     217.55   517.55   19992.                        0.00   5938.5
             76.26   270.00           93.31   292.05
              0.00                   4667.6   201.15      14891.   130.18
            223.74                                         61.03
```

Figure 6.8 cont.

6.51

```
400.00      0.00     0.00   20006.                          0.00   2879.4
            0.00   270.00              90.46    423.97
            0.00                      4521.8    284.27    20829.   179.16
            0.00                                           90.11

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

500.00     74.32   515.37   19983.                          0.00   5869.2
            0.00   270.00              87.45    541.72
          225.68                      4375.9    354.17    27396.   218.50
          215.37                                          118.82

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

600.00      0.00   141.25   20010.                          0.00   2317.5
            0.00   270.00              79.66    663.79
            0.00                      3980.8    399.68    31121.   244.26
          141.25                                          135.74

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

699.99     86.87   372.45   19996.                          0.00   4393.3
            0.00   270.00              64.39    759.10
          213.13                      3219.9    422.59    32678.   257.43
           72.45                                          141.37

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

799.99    161.65   212.33   19212.                          0.00   2206.6
            0.00   270.00              44.67    830.60
            0.00                      2325.3    439.19    32678.   267.67
           50.68                                          141.37
```

Figure 6.8 cont.

6

```
PM1=1,PM2=2,PM3=3,PM4=4

  0.000      62.500     125.000     187.500     250.000  1234
  0.02 - - - - 4 . - - - - - . - -1- - - . - - - - - . 13
     3         4 .           .       1   .           2
     3          4.           .          1.          2.
     3           4           .           . 1       2 .
     3           .4          .           .   1   2   .
     2           .           .           .      1    . 234
     2           .           .           .        1  . 234
     2           .           .           .         1 . 234
     1           .           .           .           . 1234
     3           .           . 4    2    .           1
200.02 - - - - - . - - - - - . - - - - - . - - - - - 1 234
     3           .           .2      4   .           1
     3           .         2 .          4.          1.
     2           .           .           . 4       1 . 23
     1           .           .           .    4      . 123
     3           .  2        .           .     14    .
     1           .           .           .        4  . 123
     1           .           .           .           . 1234
     1           .           .           .          4. 123
     1           .           .           .           4 123
400.01 - - - - - . - - - - - . - - - - - . - - - - - . 1234
     1           .        $   .          .           4 123
     .          2.         1 .           3          4.
     .           2      1    .           .  3     4  .
     1           .           .           .       4   . 123
     2           . 1         .           .    4 3    .
     2           1           .           .  4     3  .
     1           .           .           4           . 123
     2         1 .           .        4  .          3.
     2         1 .           .     4     .           3
600.01 - - - - - . - - - - - . -4- - - - . - - - - - . 123
     2         1 .           4           .          3.
     2          1.        4  .           .           . 23
     2           .1    4     .           .           . 23
     2           . 1 4       .           .           . 23
     2           . 4  1      .           .    3      .
     2           4      1    .           . 3         .
     2          4.         1 .           3           .
     2         4 .           .1       3  .           .
     2         4 .           .   1 3     .           .
800.02 - - - - 4 . - - - - - . - - -1- - . - - - - - . 23
```

Figure 6.8 cont.

```
 LST=L,ACS=C,CST=N,PTS=*

  0.000T      5.000T     10.000T     15.000T     20.000T L
  0.000M     50.000M    100.000M    150.000M    200.000M C
  0.000T      2.000T      4.000T      6.000T      8.000T N
  0.000     200.000     400.000     600.000     800.000  *
  0.0L - - - - - . - - - - - . - - - - - . - - - - - . LCN*
     *    C      . N     L   .           .           .
     *        C  .    N      .     L     .           .
     *           .C     N    .           .    L      .
     *           .  C   N    .           .           L
     .           .* C   N    .           .           L
     .           . * C    N  .           .           L
     *           .      C    N           .           L
     *           .     C    N.           .           L
     *           .    C   N  .           .           L
200.0. - - - - - . -*-C- -N- . - - - - - . - - - - - L
     *           .         C .   N       .           L
     *           .         C .  N        .           L
     .           .          C. *  N      .           L
     .           .*         C.   N       .           L
     *           .         C .   N       .           L
     .           . *        C.    N      .           L
     *           .           .C     N    .           L
     *           .           C     N     .           L
     *           .          C.    N      .           L
400.0* - - - - - . - - - - C . -N- - - - . - - - - - L
     *           .        C  . N         .           L
     *           .         C .  N        .           L
     *           .        C  .  N        .           L
     .           . *     C   .N          .           L
     *           .        C  . N         .           L
     *           .         C .  N        .           L
     *           .         C .   N       .           L
     *           .          C.    N      .           L
     *           .        C  . N         .           L
600.0* - - - - - . - - -C- - N - - - - - . - - - - - L
     *           .     C    N.           .           L
     *           .    C   N  .           .           L
     *           .   C   N   .           .           L
     *           .   C   N   .           .           L
     *           .  C   N    .           .           L
     *           . C   N     .           .           L
     *           .C  N       .           .           L
     *           C  N        .           .           L
     *.         C. N         .           .           L
800.0* - - - - -C. N - - - - . - - - - - . - - - - L .
```

Figure 6.8 cont.

SECTION 7

LOSS CONTROL ECONOMICS

An internal loss control strategy should optimize the effectiveness and cost of the effluent management system. It may or may not show a positive economic return. It may, however, represent the least cost approach to producing an effluent of desired quality when considering the cost of alternatives available in external treatment.

The economics of internal process loss control are mill specific. Construction costs for installing a system can be expected to vary widely depending on relative ease with which sewer systems can be isolated and/or rerouted and space available for storage. In the case of controlling cooking liquor losses, the economics are dependent on adequate steam generating capacity and recovery furnace capacity. Even when these are all or partially available, they have a value for incremental pulp production which must be weighed against the value of using this capacity for other purposes.

The full evaluation of the economics of a loss control strategy is beyond the scope of this study. However, the potential return which can be used to offset the installation and operation of such a system can be computed from a knowledge of the flow and chemical content of the process sewers. An example is shown in Figure 7.1 using data from an actual mill situation and relationships presented earlier.

The mill recovered and processed over 4 million gallons of strong spills in a period of one month. Strong spills were defined as those having a conductivity greater than 8 mmhos/cm and these spills were contained and eventually returned to the weak black liquor system. Using the aforementioned information, computations show the benefit of recovering this material.

Figure 7.1 shows that over one million pounds of solids, having a total heat value of 6000 MBtu and containing a quarter of one million pounds of sodium, was recovered and nearly a quarter of a million pounds of BOD did not have to be treated at the wastewater treatment plant. These data can be assigned monetary values. The relative return, disregarding any value that might be assigned to the lost production capacity in process equipment or any operational and maintenance costs for the operation of the spill control system, amounted to more than $48,000 or $1.84 per ton of pulp produced in the period, using the assumptions and unit costs shown in the figure and this can be used to offset the cost of installing such a system at this mill.

Figure 7.1 Example of Spill Recovery Operating Cost Offsets

Recovered 4,230,600 gal of strong spills having a conductivity ≥ 8 mmho/cm

ASSUME - TS = 2.9(Cond) BOD = 0.23(TS)
Na = 0.71(Cond) Cond = 10 mmho/cm

THEREFORE - TS = 29 gm/l or 2.9% = 1.0224M lbs
BOD = 235.15K lbs
Na = 250.3K lbs = 772.7K lbs as Na_2SO_4

VALUE OF ABOVE -

BOD Treatment cost @ 5¢/lb = $11,758
Na @ $85/ton Na_2SO_4 = 32,840
TS 5870 $\frac{\text{Btu}}{\text{lb}} \times \frac{\$2.06}{\text{MBtu}}$ = 12,363

$56,961

But have to evaporate to 50% solids

$$4230600 \times 8.34(0.97 - 0.5)\text{lbs } H_2O \ \frac{1 \text{ lb stm}}{5 \text{ lbs } H_2O} \times \frac{1100 \text{ Btu}}{0.85 \text{lb stm}} \times \frac{\$2.06}{\text{MBtu}}$$

= $ 8,842

Therefore NET BENEFIT = $48,119
or at 26,144 tons = $1.84/ADT

Another question related to loss control strategy economics is that of the minimum concentration of solids which it is feasible to recover assuming some means of dealing with the extra water; for example, extra evaporation capacity or use of the recovered spills for brownstock washing, thus concentrating them in or adding them to the weak black liquor system. The latter strategy may be desirable with the additional flexibility to put them into any stage of washing, depending on their concentration.

Figure 7.2 presents an example of the calculation of the minimum recoverable solids. The example equates the cost of evaporating the water from the recovered spills, which is derived from the assumptions shown at the top of the Figure, to the value of the recovered material, which is also shown under the assumptions. The concentrations of Na, BOD and TDS are then converted to their dollar value per thousand gallons for a 1 mg/1 concentration. This computation shows that sodium is the most valuable component of the recovered material.

The components are written in terms of their conductivity relationships (derived in the analytical portion of the LCS project to put them on a common basis) and these relationships are then added and equated to the break even cost of evaporating the water from the recovered spills. This results in a minimum conductivity of about 8 mmhos/cm for this particular example. When this conductivity is used to determine the solids concentration, it is seen that it is economically feasible to recover spills having a solids concentration of 15 gm/1 or 1.5%. Calculations made independently by several mills cooperating with this project agreed with this concentration. Given that production equipment is available, the recovery of spills from the pulping, washing and recovery areas appears possible where solids

FIGURE 7.2 Example Calculation Minimum Recoverable Solids

ASSUMPTIONS:

Evaps - 5 lbs H_2O/lb steam, 1100 Btu/lb of steam

Oil cost \$13/bbl, 0.15 MBtu/gal = \$2.06/MBtu

At a steam generating efficiency of 85%, it costs 53.41¢ to evaporate 1000 lbs of H_2O or \$4.45/Kgal.

Recovered solids contain 5870 Btu per dry lb.

Saltcake costs \$85/ton

Removal of one lb of BOD at WWT cost 5¢.

THUS:

$$\frac{\text{Na lb}}{\text{120 Kgal}} \times \frac{\$85}{\text{2000 lbs}} \times \frac{\text{142 lbs Na}_2\text{SO}_4}{\text{42 lbs Na}} = 1093 \times 10^{-6} \text{ Na \$/Kgal·mg/l}$$

$$\frac{\text{TOC lb}}{\text{120 Kgal}} \times \frac{\text{0.6 lb BOD}}{\text{lb TOC}} \times \frac{\$0.05}{\text{lb}} = 250 \times 10^{-6} \text{ TOC \$/Kgal·mg/l}$$

$$\frac{\text{TDS lb}}{\text{120 Kgal}} \times \frac{\text{5870Btu}}{\text{lb}} \times 0.85 \times \frac{\$2.06}{\text{MBtu}} = 85.65 \times 10^{-6} \text{ TDS \$/Kgal·mg/l}$$

FROM RELATIONSHIPS:

Na = 269(Cond) - 75

TOC = 509(Cond) - 170

TDS = 1839(Cond) - 354

What is the minimum conductivity to break even in this example?

$$\$4.45/\text{Kgal} = (((1093\text{x}10^{-6}(269C - 75) + 250\text{x}10^{-6}(509C - 170) + 85.65\text{x}10^{-6}(1839C - 354))) \text{ \$/Kgal}$$

$$4.45 = 578.9\text{x}10^{-3}C - 154.8\text{x}10^{-3}$$

$$C = 7.96 \text{ mmho/cm}$$

$$\text{TDS} = 1.43\%$$

THUS: It is possible to recover economically liquors containing approximately 1.5% solids.

concentrations are in the range of 1% to 2%. The exact concentration will depend on such things as type of pulp produced, the options available for the disposition of the recovered material and the existence of sufficient capacity to evaporate the water.

The economics of providing extra evaporation, steam generating or liquor recovery capacity to concentrate the recovered low solids discharge must be quantified. The cost of extra process equipment and utilities is compared with any benefit obtained to arrive at a net cost or benefit.

Boatwright (1) provided the following information for a 1000 tpd mill evaporating 15% solids WBL to a 50% solids product having 3000 pounds of solids per ton of production.

No. of Effects	Economy lbs H_2O/lb steam	Heat Required MBtu/1000 ton	Steam Cost M$/yr
4	3.5	4000	3.60
5	4.4	3182	2.88
6	5.0	2800	2.52
7	5.5	2545	2.29

Cost of additional effect	$750,000
Depreciation	38,000
Maintenance and power	20,000

Annual savings:

5 effect steam cost	$2,880,000
6 effect steam cost	-2,520,000
Saving	360,000
Depreciation	-38,000
Maintenance and power	-20,000
Net annual saving	$302,000

Using this information, it can be calculated that in going from five effects to six, but using the same amount of steam for the six effects, the evaporators would handle an extra 1910 pounds or 229 gallons of water per ton of production at a cost of $58,000 annually for depreciation, maintenance and power.

However, if the 229 gallons represent the material recovered from spills, with the characteristics noted in Figure 7.2 with a conductivity of 8 mmhos/cm, the following savings could accrue.

Annual savings:

5 effect steam cost	$2,880,000
6 effect steam cost	-2,880,000
Savings	0
Saltcake (Na)	182,000
BOD not treated	78,200
Heat value of solids	98,600
Savings	358,800
Depreciation	-38,000
Maintenance and power	-20,000
Net annual saving	$300,800

Thus the values of the recovered material would result in a 40% return on investment or a payoff period of about 2.5 years.

Similar calculations can be made for a specific mill situation for which no assumptions will have to be made since all of the essential factors; such as costs of makeup chemicals, fuel and wastewater treatment; heating value of liquor solids; evaporator capacity, and characteristics of process discharges which constitute spills, are known.

An investigation of the factors involved in designing a loss control strategy will aid in deciding the economic feasibility of alternative courses of action. These will include segregation of dissimilar process discharges such as causticizing area losses and separation of clean waters such as seal and cooling waters. The economics may point to separate preconcentration of the relatively dilute losses prior to evaporation; for example, by use of vapor compression evaporation, freeze concentration or a membrane process, on a small scale.

With the escalating costs of energy and consequently all other raw material and operating costs, the retention of process materials and the optimum operation of all processes, including wastewater treatment, becomes readily justifiable on an economic basis.

REFERENCES

1. Boatwright, W.H., "Chemical Recovery Systems and Energy Considerations," 19th Annual Pulp and Paper Summer Institute, University of Maine at Orono, June, 1978

SECTION 8

APPLICATION OF LOSS CONTROL STRATEGY AT BROWN COMPANY

DESCRIPTION OF MILL AND CONTROL SYSTEMS

The Brown Company kraft mill in Berlin, N.H. was chosen as the site in which the computer would be installed and the effectiveness of the loss control strategy studied. Among the reasons for this choice were Brown Co.'s interest and willingness to host the demonstration project and the fact that Brown Co. was in the process of installing a loss control system for their kraft mill, which was to include appropriate sensors to monitor process sewers and tank levels. The sensors were all to be wired to a central panel in the technical services area and the signals from the sensors would all be standard 10-50 ma and compatible for input to a digital computer.

The Burgess Division mill of Brown Company in Berlin, N.H. produces 700 tons of bleached hardwood and softwood kraft pulp and 200 tons of NSSC pulp per day. Kraft pulp is produced in nine batch digesters, blown to one of two blow tanks equipped with a modern blow heat recovery system and washed on three lines of three countercurrent vacuum drum washers. The washed pulp is then screened and sent to high density storage prior to bleaching in two CEDED bleach plants. Weak black liquor is recovered from the first stage washer filtrate tanks and sent to storage after mixing with NSSC spent liquor. From the weak black liquor storage tanks, it is pumped to two sets of multiple effect evaporators for concentration prior to oxidation, use in the recovery furnace evaporator-scrubbers, and eventual burning in the two recovery furnaces for recovery of heat and inorganic chemicals.

The stations selected for monitoring are in the pulping and recovery areas of the mill relatively close to specific unit processes; thus, the reasons for increases in flow and conductivity can be quickly and easily recognized. The arrangement of the spill collection sumps is shown schematically in Figure 8.1.

Station 1 (SN 1) receives drainage from the area in which are located the nine batch digesters, the two blow tanks, the IMPCO and Oliver three stage brown stock washers (BSW) and associated filtrate tanks, liquor transfer and recirculation pumps, foam towers and stock pumps.

SN 2 receives drainage from the area in which are located the Oliver and Swenson three stage BSW's and filtrate tanks, the 20,000 gallon overflow tank, the knot tank, the foam tank, and associated pumps and valves.

SN 3 receives drainage from the area in which are located No. 8 recovery boiler and smelt dissolving tank (SDT), No. 8 heavy black liquor (HBL) tank, knot tank, associated pumps and agitators and two sets of multiple effect evaporators (MEE) with associated feed, transfer and condensate pumps.

SN's 1, 2 and 3 normally overflow to the main kraft sewer which flows through a Parshall flume at Station 4 in the lift station where it combines with the causticizing and screen room sewers and is pumped to the Burgess total effluent sewer for gravity flow to the activated sludge wastewater treatment plant.

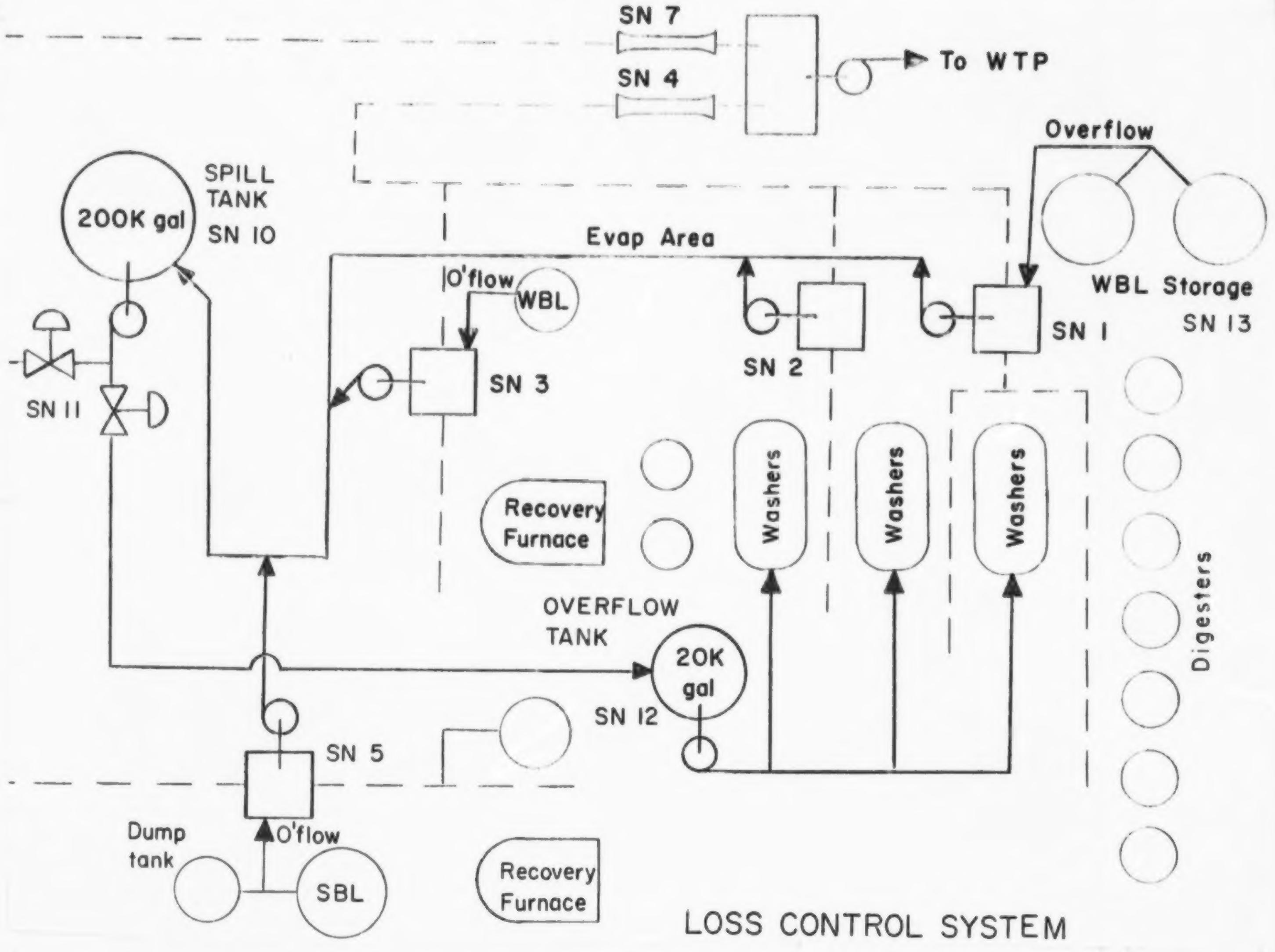

SN 7
SN 4
To WTP
Overflow
SPILL
TANK
200K gal
SN 10
Evap Area
O'flow
WBL
SN 3
SN 2
SN 1
WBL Storage
SN 13
SN 11
Recovery
Furnace
Washers
Washers
Washers
Digesters
OVERFLOW
TANK
20K
gal
SN 12
SN 5
Dump
tank
O'flow
SBL
Recovery
Furnace
LOSS CONTROL SYSTEM

Figure 8.1 Schematic of Brown Co., Loss Control Strategy System

8.4

SN 5 receives drainage from the area in which are located No. 11 recovery boiler and SDT, the NSSC liquor tank, a foam tank, pumps associated with the venturi evaporator-scrubber, the black liquor oxidation system, boiler feed-water treatment and demineralizer and pumps associated with the foregoing. SN 5 normally overflows to the causticizing sewer which flows through a Parshall flume at the lift station as previously described.

All four sumps are equipped with sump pumps which will pump spills through a common header to the new 200,000 gallon spill recovery tank (SRT). The pumps can be activated manually, by a conductivity set point or by a signal from the computer. Flow into the sumps is measured by a rectangular weir and level sensor. Conductivity at each sump is monitored and recorded. The pumps utilized in the spill control system are described in Table 8.1.

TABLE 8.1 SPILL CONTROL SYSTEM PUMPS

SN	gpm	Head-ft	horsepower	rpm
1	250	60	10	1750
2	250	55	10	1750
3	250	55	10	1750
5	250	50	7.5	1750
10	300	35	7.5	1150
12	300	50	25	1770
12	1000	101	-	1175

Piping from the sumps to the spill recovery tank ranges from 4 inch to 8 inch diameter welded stainless steel. Total length from SN 1 to the SRT is 542.3 feet with a difference in elevation of 40.7 feet. There are 22-90° elbows and 13-45° elbows making an equivalent hydraulic pipe length of 885 feet.

Piping from the spill recovery tank to the existing overflow tank in the mill is 4 inch diameter welded stainless steel with a total length of 416.5 feet and a net change in elevation of 13.25 feet from the SRT to the overflow tank. There are 16-90° elbows and 2-45° elbows making an equivalent hydraulic pipe length of 538.5 feet. In addition, there is a wafer or butterfly control valve after the discharge of the spill recovery pump which controls the rate of return of recovered material.

The level and conductivity of the 200,000 gallon spill tank contents are monitored and recorded. The contents of the tank can be recirculated, bled to the main kraft sewer or pumped to the existing 20,000 gallon overflow tank and thence to the first stage of the BSW's for recovery in the weak black liquor system. The disposition of the spill recovery tank contents is controlled by the two butterfly control valves on the discharge side of the spill recovery pump. The pump on the discharge side of the spill recovery tank is designated as SN 10 and the values as SN 11. A schematic elevation of the spill recovery tank is shown in Figure 8.2.

When utilizing computer control, the flow and conductivity will be related to the contents of the sewer flow at each sump and the pumps will be activated based on the mass of material to be recovered as described elsewhere in this report. The spill tank will also be monitored and disposition of the contents will be made by the computer based on the level of the overflow tank, the inventory of weak black liquor and the characteristics of the material in the spill tank.

P.6

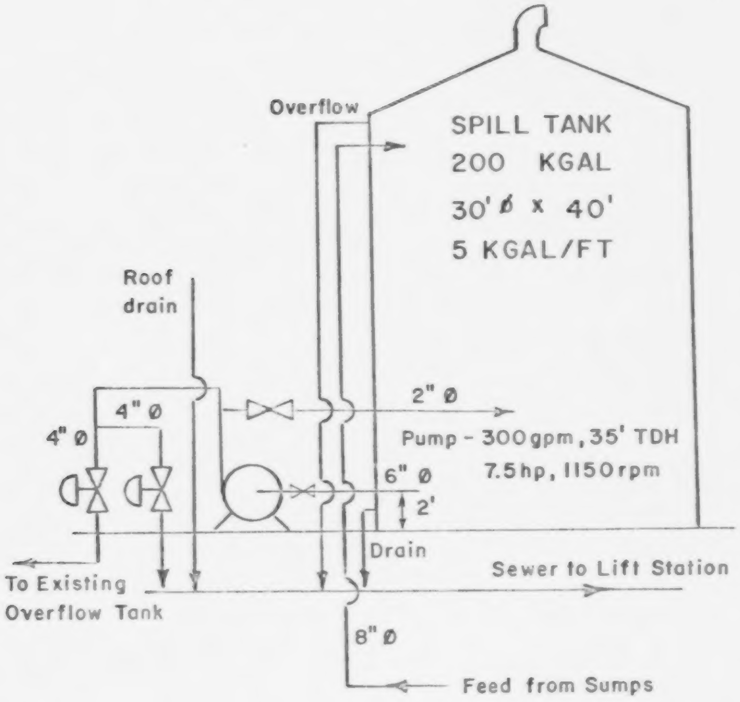

Overflow
SPILL TANK
200 KGAL
30'Ø x 40'
5 KGAL/FT
Roof drain
4" Ø
4" Ø
2" Ø
Pump - 300gpm, 35' TDH
7.5hp, 1150rpm
6" Ø
2'
Drain
Sewer to Lift Station
To Existing Overflow Tank
8" Ø
Feed from Sumps

Figure 8.2 Schematic Elevation of Brown Co. Spill Tank

COMPUTATIONAL SYSTEMS

General

The basic purposes of the computerized spill control system are threefold: 1) to have the computer gather sensor data; 2) to have the computer analyze the sensor data for loss detection and data logging purposes; and 3) to have the computer effect real-time control to react to a detected loss by queueing remote control devices and/or notifying the system operator.

The arrangement of the hardware used to achieve the above functions is schematically presented in Figure 8.3. The remote sewer sensors monitor various parameters; e.g., conductivity and flow, and the signals from the sensors are directed, via proper interfacing and signal conditioning, to the computer. The computer will process and analyze this information to determine if a spill or abnormal condition exists at the various points being monitored. The computer utilizes relationships appropriate to the parameter being sensed, such as the linear equations shown in Figure 5.11 to analyze the monitored data. If the results of these analyses show that the various calculated parameters are either out of or back in a predefined tolerance range, the system operator is informed of the situation via the person-machine interface (keyboard printer) and, if appropriate, the remote control devices; i.e., pumps and valves, are turned on or off depending on the situation. These pumps and valves may be used to divert a spill from the sewer to temporary storage in the spill collection tank or to recover previously stored spills.

The above description of the information flow through the system hardware explains the basic procedure followed by all information and control

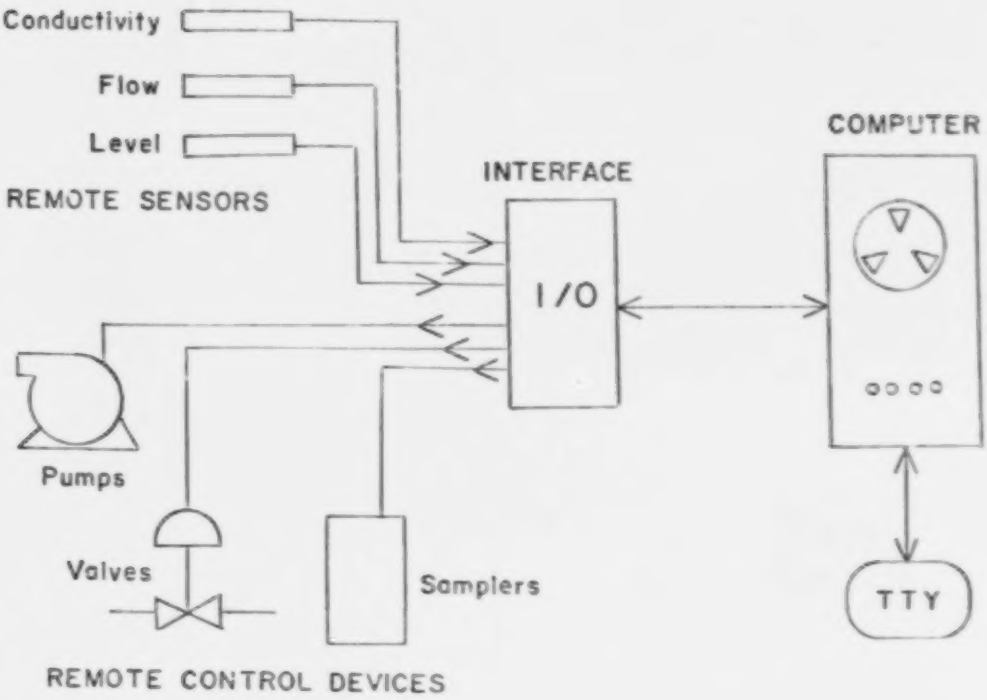

Conductivity
Flow
Level
REMOTE SENSORS
INTERFACE
I/O
COMPUTER
TTY
Pumps
Valves
Samplers
REMOTE CONTROL DEVICES

Figure 8.3 Schematic of LCS Hardware Arrangement

in the loss control system. That description is but one example of the control effected by the system. The system will also monitor the status of the spill tank and coordinate the spill tank's status with the timing of the spills pumped to the tank. Many other functions, such as record keeping, are also performed by the system. The major point is to show the coordinated control which will be achieved with the computerization of the spill control system. Figure 8.1 shows the spill system as it is configured at Brown Company.

Hardware Selection

Table 8.2 is a summary of the minicomputers investigated during a survey of commercial minicomputer vendors. As can be seen from this Table, the majority of the minicomputers have very similar characteristics. It can be said that all the computers listed here would suffice for this application. Each have some strong and weak points but all are more than adequate. How then does one decide which to choose? The major factors to consider are: reliability, ease of programming, availability of software operating systems, memory capacity for further growth, and machine cost. Reliability data is difficult to obtain from the manufacturers as can be seen from the many blanks in the mean time between failures (MTBF) column in Table 8.2. This consideration generally becomes a result of the user's experience. In this light, the machines from Digital Equipment Corporation (DEC), Data General, and Hewlett-Packard are rated the most trustworthy. Each manufacturer also claims that programming their machines is simple. In most cases this is true. A comparison of the columns on word instruction length, number of directly addressable words, assembly language instruction repertoire, hardware registers/number of bits, and the interrupt structure gives one the idea of ease of programming. Each manufacturer listed in Table 8.2 offers off-the-shelf operating system to support their computer hardware. Operating systems from each vendor were evaluated in the light of this specific application. The column headed Software Operating Systems shows the results of this analysis. In this respect, DEC and Hewlett-Packard are felt to be the best. Memory capacity of all these machines is certainly adequate and all can be increased beyond the maximums specified with the addition of appropriate control devices. A mass storage device was not included in this analysis because such a device is available for each system at the same price and reliability. The only computer that may come close to a memory limit under its present configuration is the IBM System 7. The costs, based on 32,000 words of memory, are self-explanatory, eliminating the IBM System 7. With all these factors in mind, the vendors were rated in the following order: 1) Digital Equipment PDP-11/04, 2) Hewlett-Packard 2100A, 3) Data General Nova series.

The vendor whose equipment was chosen for implementation of the LCS project was Digital Equipment Corporation (DEC). They were not only first in the above analysis but also have a well established local and national service and maintenance organization which becomes a prime factor when equipment is placed in the field. DEC also is the only vendor which supplies an input/output interface system totally compatible with the LCS requirements. They also guarantee the interface of this equipment with their minicomputer.

The current trend in the real-time computer applications field is the substitution of minicomputer based systems with microcomputer based systems. Therefore, the DEC LSI-11 and the Data General Micronova were both investigated. At the time the choice was being made (early 1976) the software and

TABLE 8.2 MINICOMPUTER EVALUATION AND COSTS

Manufacturer/ Model	Word Instruction Length (bits)	Word Cap. Min/Max	Number of Directly Addressable Words	Input/Output Word Size	Cycle Time Uses/Time	Instruction Repertoire (Number Inst.)	Addressing	Hardware Registers/ # of bits	Reliability			Approximate Price (based on 32K of Memory**)
									MTBF*	Maintenance Contract	Software Operating Systems / Rating	
Digital Equipment Corp. (DEC)/ PDP-11/04	16,16/32/48	4096/28,692	28,672	16	0.9	70	Indirect	8/16	N/A	Yes	RT11/ Excellent	$16,000
DEC/PDP-11/10	16,16/32/48	4096/32,768	32,768	16	0.9	70	Indirect	8/16	N/A	Yes	RT11/ Excellent	18,000
DEC/PDP-11/35	16,16/32/48	8192/124K	32,768	16	0.85	75	Indirect	8/16	N/A	Yes	RT11/ Excellent	23,000
Data General Nova 840	16,16	2048/131,072	1,024	16	0.8	32	Indirect	4/16, 1/15	7250	Yes	RDOS/ Good	16,500
Data General Nova 2	16,16	2048/24,576	1,024	16	0.8	32	Indirect	4/16, 1/15	N/A	Yes	RDOS/ Good	15,000
Texas Instrument **** 980A	16,16/32	4096/65,536	65,536	16	0.75	98	Indirect	8/16	N/A	Yes	PAMD/ Good	14,000
Hewlett Packard 2100 A	16,16	4096/32,768	2,048	16	0.98	80	Indirect	5/16	N/A	Yes	RTE-III/ Excellent	17,000
IBM System 7	16,16/32	2048/16,384	16,384	16	0.4	40	Direct	60/16	N/A	Yes	System 7/ Fair	35,000
Interdata 7/16	16,16/32	4096/32K	32,678	16	1.0	104	Indirect	15/16	N/A	Yes	OS-16 MT2/Good	14,000

N/A-Not Available, *MTBF-Mean Time Between Failures in Hours, ** Memory-Extra Core Memory

***RTC-Programmable RTC, ****Semiconductor Memory Used Rather than Core peripheral equipment support, as well as product delivery schedules, were not compatible with the LCS project. However, due to the rapid development in both hardware and software and the constantly decreasing costs of microprocessor technology, a future installation of this type would most likely be based around a microprocessor.

Hardware Design

The hardware for the loss control system constitutes the physical equipment required to achieve the purposes of the system. Hardware design has been approached in a modular fashion. Hardware modularity will allow for easy addition or removal of hardware modules with minimum impact on the system performance. All hardware will be off-the-shelf equipment.

Hardware Specifications

The hardware used in the computer system for the Loss Control Strategy project is defined in three areas. The first is the computer and its peripheral equipment; the second is the computer Input and Output (I/O) interface hardware; and the third area is comprised of the sensors and control equipment.

Computer and Peripherals --

Figure 8.4 is a block diagram of the computer and its peripheral equipment. All equipment specified is supplied by Digital Equipment Corporation (DEC) including the keyboard printer. There are three major reasons for using an all DEC hardware configuration. The first reason is that DEC can guarantee the interface of its own equipment which will help eliminate any hardware startup problems. The second reason is that DEC provides off-the-shelf software for the appropriate hardware devices. This eliminates the need to write hardware drivers. The third major reason for going with all

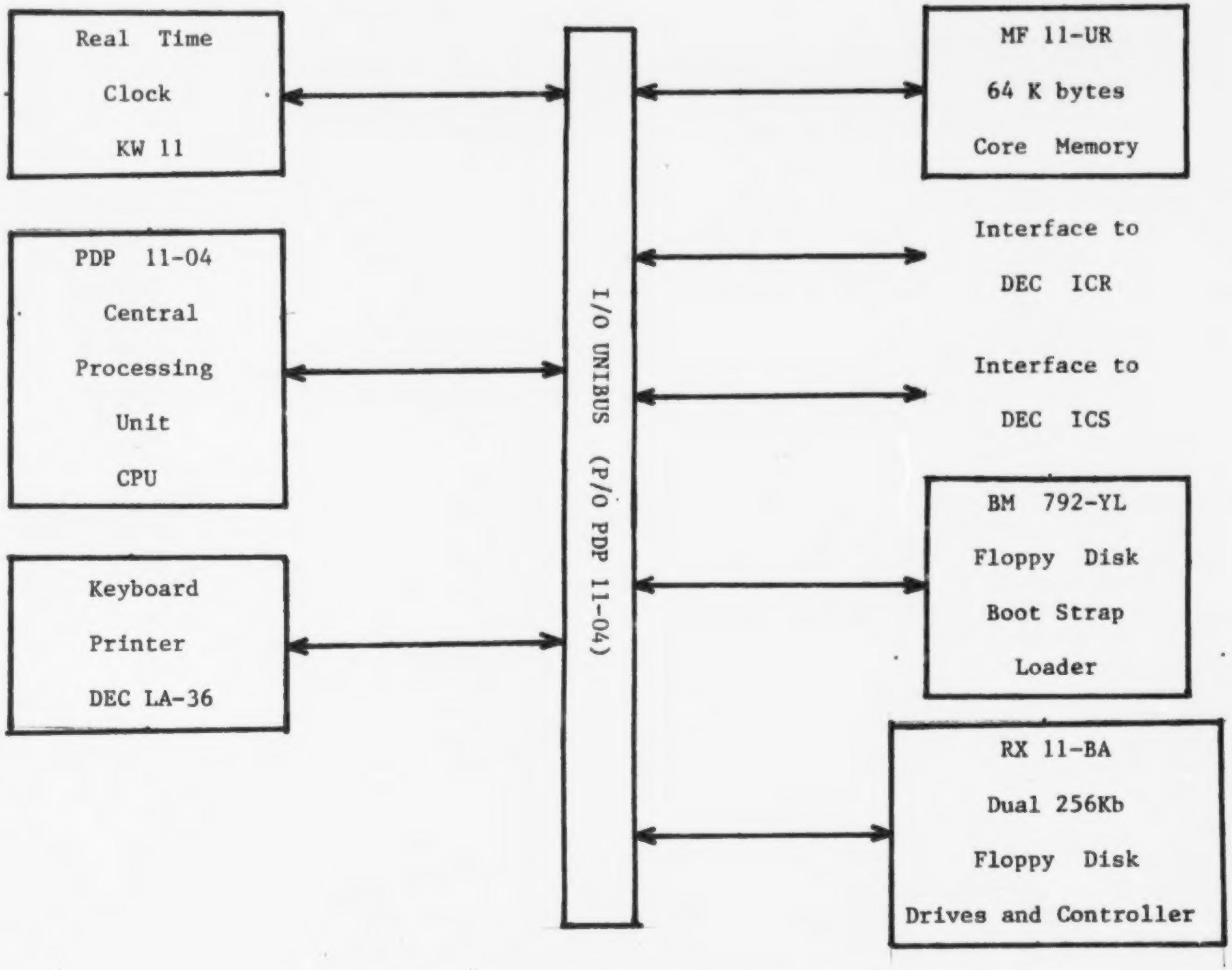

Real Time
Clock
KW 11
PDP 11-04
Central
Processing
Unit
CPU
Keyboard
Printer
DEC LA-36
I/O UNIBUS (P/O PDP 11-04)
MF 11-UR
64 K bytes
Core Memory
Interface to
DEC ICR
Interface to
DEC ICS
BM 792-YL
Floppy Disk
Boot Strap
Loader
RX 11-BA
Dual 256Kb
Floppy Disk
Drives and Controller

Figure 8.4 Computer and Pheripheral Equipment

DEC is that they provide maintenance service on all of their hardware. This consideration becomes a prime factor when the equipment is put in the field.

Following is a description of the hardware outlined in Figure 8.4.

Central Processing Unit (CPU)-The CPU is a DEC PDP 11-04. The I/O Unibus is part of this piece of equipment.

Core Memory--Although memory is an integral part of the computer system, DEC supplies it on an optional basis. The sixty four thousand byte (32 k words) MF11-UR has been allowed for in this application.

Interfaces to DEC ICR--The signal path represents the Unibus to Industrial Control Remote (ICR) interface wiring.

Boot strap loader--The BM792-YL is a read only memory (ROM) which automatically loads the program resident on the floppy disk when the computer is powered up.

Dual two hundred fifty six thousand byte (256kb) floppy disk drivers and controller--The RX11-BA dual floppy disks are used for mass storage of data and for program load and storage. One disk (DX0) is dedicated to program load and storage and during the normal system run mode is used as a "read only" device. The other disk (DX1) is used for data mass storage and is configured for both read and write operations. The separation of disk use insures that a protected copy of the program will always be resident within the computer system.

Keyboard printer--This device is used for system message logging and operator-system interface. The unit is a DEC LA36.

Real-Time (RTC)--The KW11 RTC is used by the system to provide time of day, date and event scheduling functions.

Input and Output (I/O) Interface Hardware--

Input and Output capability is provided by DEC supplied off-the-shelf hardware. The Industrial Control Subsystem Remote (ICR) is an off-the-shelf DEC hardware module which provides state of the art process interface for control and/or monitoring of typical industrial transducers. Equipment within one hardware system provides the ability to conveniently interface DEC computer systems to industrial analog and digital signals and provides the capability to be located up to 6000 feet from the host processor. The ICR operates under program control as an I/O device capable of interrogating both digital and analog inputs and driving both digital and analog outputs. Within each mode as many as sixteen modules of any mixture may be supported. Each digital I/O module contains 16 bits of input or output data; thus in one subsystem a maximum of 256 digital points of various types may be supported. The analog to digital (A/D) converter module provides for 9 channels of input and may be expanded to 120 channels per A/D converter with the use of 16 channel expander multiplexers. A total of 12 ICR subsystems can be interfaced to a single computer.

A full complement of functional I/O modules is available for the ICR including ac and dc sense and interrupt inputs, I/O counters, steady state and single shot ac and dc outputs, flip-flop and latching relay outputs, analog to digital converters, and digital to analog converters.

The I/O card configuration for the ICR in the Brown Co. system consists of four I/O modules. Two of these modules (DEC #'s IAD-IA and IMX-IA) are used for analog input signals. This gives the present configuration the ability to monitor twenty-four analog input signals; e.g., conductivity, flow, level. The other two modules are used for signal outputs. The first is a 16-bit dc output (DEC #IDC-OA). This provides sixteen independent zero (0) or fifty (50) milliampere outputs. These outputs are used for on-off control of pumps and valves. The second output card is a 16-bit single shot dc output (DEC #IDC-OB). This provides sixteen independently adjustable zero (0) to fifty (50) milliampere pulse outputs. These outputs are being used to queue remote sewer samplers.

The present configuration of the ICR uses only four of the sixteen available module slots. This provides for easy hardware system expansion by simple addition of I/O modules.

Sensor and Remote Control Devices--

The remaining parts of the system hardware are the sensors and remote control devices. The sensors will be used to monitor the process effluents and sewer flows. They will monitor conductivity, flow and tank level. The remote control devices will be used to provide automatic flow diversion through on/off pump control and open/close valve control and to provide the ability to take sewer samples remotely.

Software Design

If the computer hardware is compared to a desk top calculator, the computer software will be analogous to the person operating the calculator. A more formal definition of software is all the programs required to direct the hardware through its functions.

General Software Design Assumptions and Considerations--

Software design has also been approached in a modular fashion. Software modularity will allow for easy addition or removal of software program modules with minimum impact on the system performance

Whenever possible, redundant processing is designed as a subroutine in order to eliminate excess coding and core usage. However, the programmer must be careful to never allow the foreground and background jobs to call the same subroutine at the same time.

The main purpose of the Loss Control Strategy project is to demonstrate that effluents from the pulping process can be monitored by a computer network; thus, the main software design effort had this purpose as its goal. This will most likely result in not including some of the additional but not essential features that a more marketable computer control system would include. Features of this type are a tamper proof operator interface, graphic and display capabilities, and advanced data analysis routines. However, these types of features can be included at a later date, if it is desirable to do so.

Software Functions--

The functions of the computer software designed as part of the Loss Control Strategy project are defined as follows:

1. Continuous gathering of sensor data.
2. Continuous set point analysis of the above information to determine if a spill or a condition detrimental to treatment exists.
3. Notification of the operator if an out of tolerance situation is encountered.
4. Determination of what should be done if corrective action is required; e.g., flow diversion.
5. Send the appropriate signal, via the hardware, to initiate the corrective action (either operator initiated or automatic).

6. If possible, determine the source of a spill and report this to the operator.
7. Perform all I/O.
8. Communicate with the operator.
9. Allow the operator to communicate with the system.

RT-11 Operating System Software--

The above software functions are implemented through the use of the DEC supplied RT-11 software operating system. The RT-11 operating system is used for two purposes; (1) software development and (2) the operating environment of the run-time program.

The software development effort consists of entering source language programs, assembling source language programs into load image code, and linking image code. Whenever possible, source language programs will be written in FORTRAN. Even though system reaction time and memory usage are increased by using FORTRAN, the saving in program coding time more than outweighs these disadvantages. When FORTRAN could not be used, assembly language was. However, the great majority of programs are written in FORTRAN.

The greatest advantage in using the RT-11 operating system comes from its use as the operating environment for the run-time programs. Using the RT-11 software in this manner allows the programmer more time to develop applications programs. The operating environment features used by the loss control system software are as follows.

Foreground/Background Job Monitor--The F/B monitor allows two programs to be run concurrently. The foreground job is run in real-time on a priority basis, and the background job is run when the foreground is idle. User and programmed requests for all services of RT-11 software are handled through

8-19

the F/B monitor.

Keyboard Monitor (KMON)--The keyboard monitor provides communication between the user at the console or keyboard printer and the RT-11 system. Monitor commands allow the user to assign local names to devices, run programs, load device handlers, and control F/B operations.

User Service Routine (USR)--The user service routine provides support for the RT-11 file structure. It loads device handlers, opens files for read or write operations, deletes and renames files, and creates new files. The Command String Interpreter (CSI) is part of the USR and can be accessed by any program to interpret a character string as a command to perform a set of USR operations.

Device Handler--Device handlers are programs which provide software support to I/O on system devices such as the keyboard printer.

Time-Scheduling Requests--This feature allows the user to easily schedule events and have program control sent to a service routine when the scheduled time occurs.

Control System Software--

The control system software will run in the environment provided by the RT-11 operating system. Whenever possible, the above mentioned features of the RT-11 will be used. Generally speaking, there can be two programs running under the F/B monitor. One program is running in real-time on a priority basis and is referred to as the foreground job. The other program runs on a time available basis; i.e., time not used by the foreground, and is referred to as the background job.

Foreground Job--The foreground job running under the F/B monitor is designed to handle the real-time functions of the loss control system software. These functions are program initialization; sensor reading; checking sensor parameters to determine if they are within tolerance; analyzing the reasons for parameters not being within tolerance; checking the status of any corrective actions taken; storing sensor readings and calculating and storing average sensor values. Foreground program initialization is outlined in Figure 8.5. There are two separate program start options specified in this figure. The first allows for a total program initialization while the second allows parameter averaging schedules to be restarted. The general structure of the foreground program is an executive scan which is looking for possible problem situations. If a problem situation is encountered, the executive transfers program control to the appropriate error analyzing routine. Figure 8.6. is a flow chart of the general structure of the foreground program. A detailed description of the functions outlined above and in this figure follows.

Sensor Reading--All sensors in the system (conductivity, tank levels and flow) which are being interrogated on a scheduled basis are read in a group or batch and their values stored. This has been done to allow different sensor values to be compared in the same relative time period. The relative time these readings were taken is saved to be used in any required confidence interval check, as explained below.

Evaluation of Sensor Parameters--After all sensor values have been read, these values are then evaluated, one at a time, to determine if they are within a predefined tolerance range. If an error is detected, program control is directed to a routine specifically designed to further evaluate the specific situation.

Applications or Error Analyzing Programs--These programs represent the

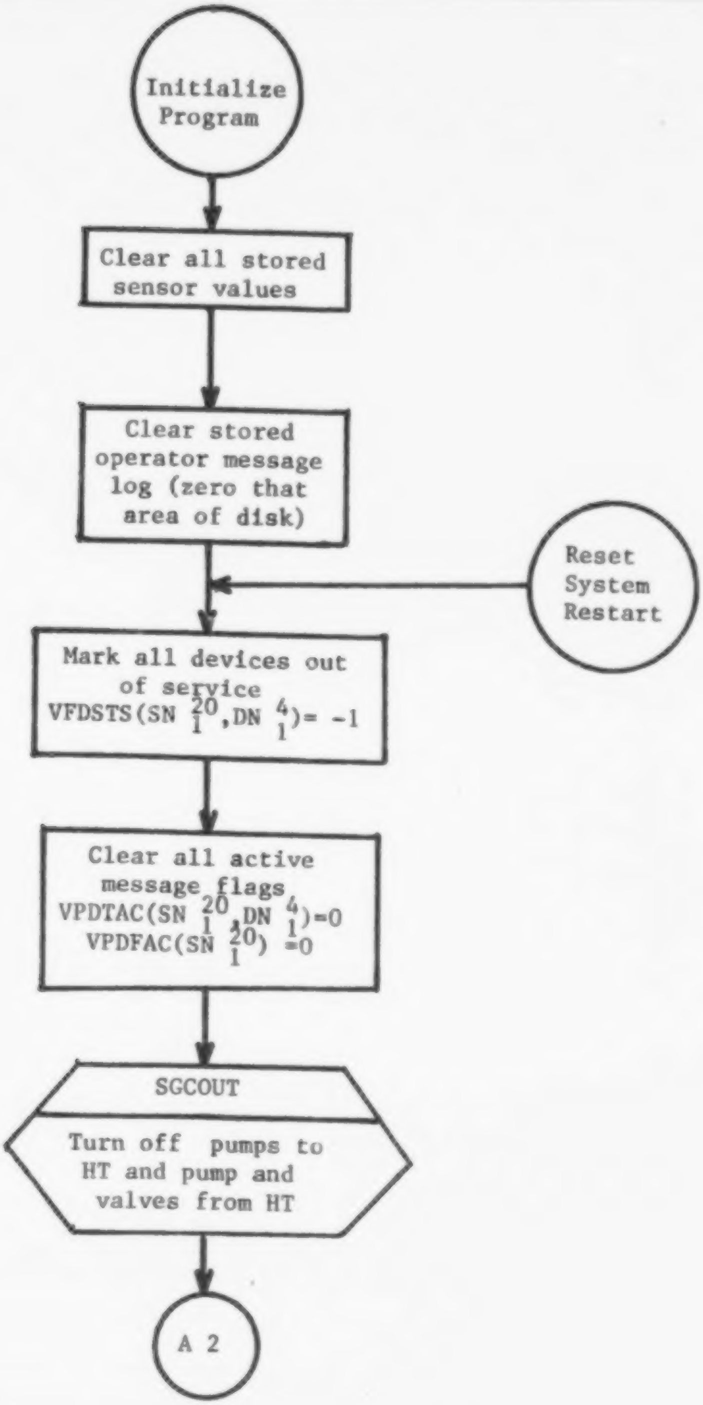

Initialize Program
Clear all stored sensor values
Clear stored operator message log (zero that area of disk)
Reset System Restart
Mark all devices out of service
VFDSTS(SN $\begin{smallmatrix}20\\1\end{smallmatrix}$,DN $\begin{smallmatrix}4\\1\end{smallmatrix}$)= -1
Clear all active message flags
VPDTAC(SN $\begin{smallmatrix}20\\1\end{smallmatrix}$,DN $\begin{smallmatrix}4\\1\end{smallmatrix}$)=0
VPDFAC(SN $\begin{smallmatrix}20\\1\end{smallmatrix}$) =0
SGCOUT
Turn off pumps to HT and pump and valves from HT
A 2

Figure 8.5 Foreground Program Initialization

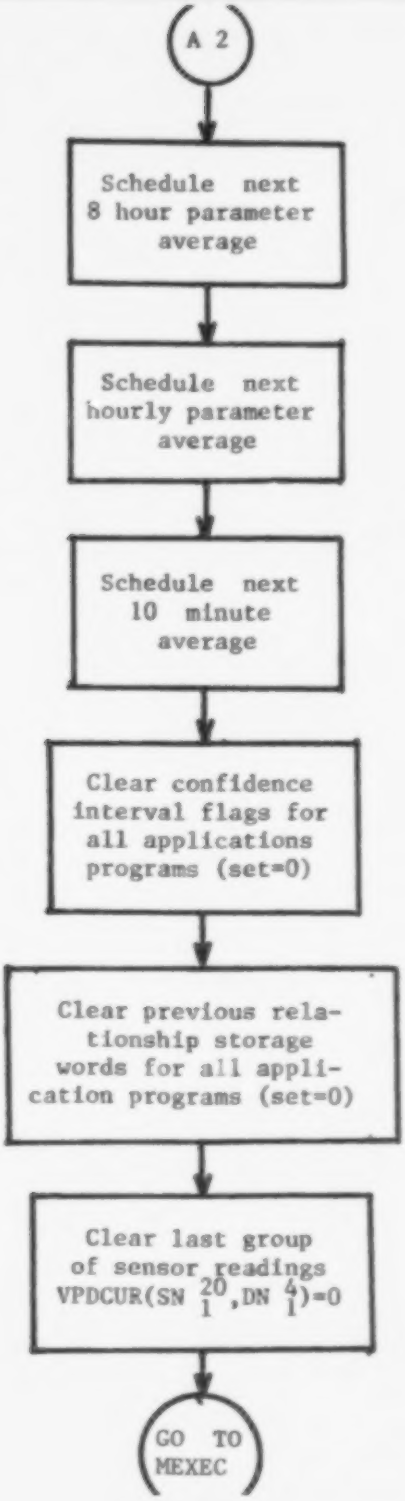

A 2
Schedule next 8 hour parameter average
Schedule next hourly parameter average
Schedule next 10 minute average
Clear confidence interval flags for all applications programs (set=0)
Clear previous relationship storage words for all application programs (set=0)
Clear last group of sensor readings VPDCUR(SN 20 1,DN 4 1)=0
GO TO MEXEC

Figure 8.5 cont.

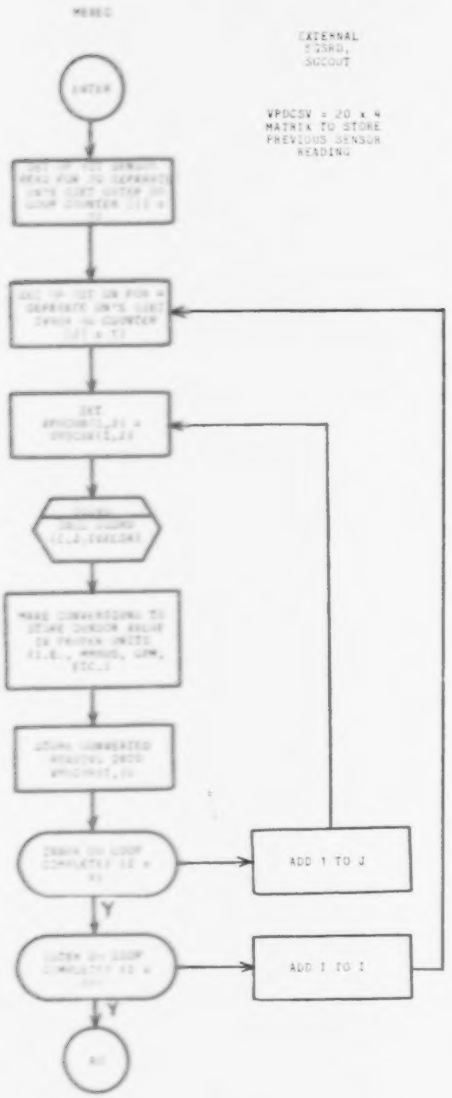

EXTERNAL
SGCOUT
VPDCSV = 20 x 4
MATRIX TO STORE
PREVIOUS SENSOR
READING
ADD 1 TO J
ADD 1 TO I
Y
Y

Figure 8.6 General Structure of Executive Program

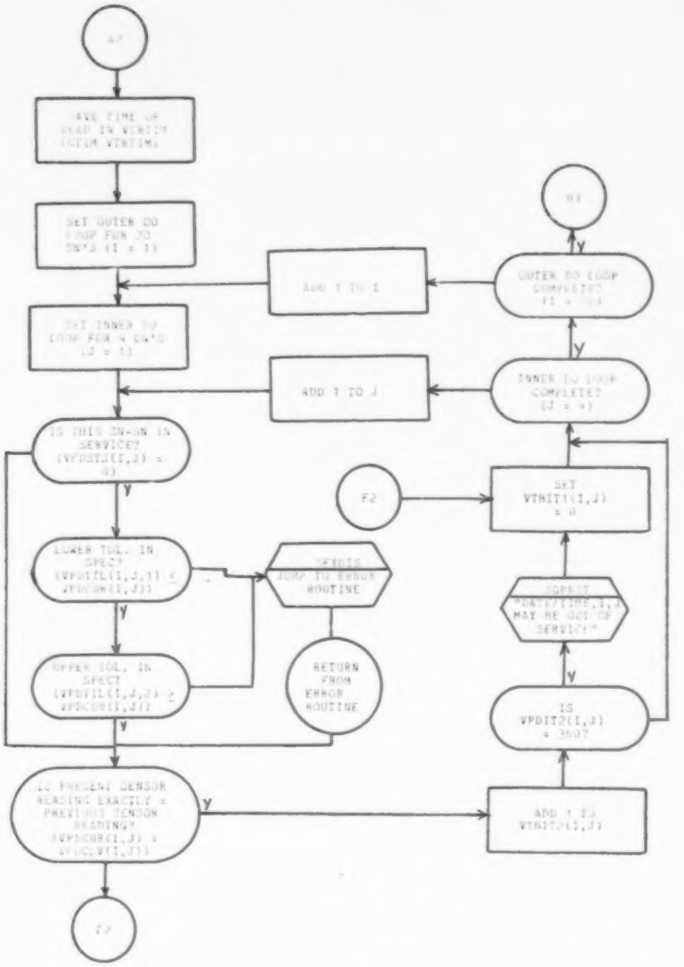

A2
SAVE TIME OF READ IN VTRTIM (ITIM VTRTIM)
SET OUTER DO LOOP FOR 20 SN'S (I = 1)
SET INNER DO LOOP FOR 4 DN'S (J = 1)
IS THIS SN-DN IN SERVICE? (VPDSTS(I,J) = 0)
Y
LOWER TOL. IN SPEC? (VPDTIL(I,J,1) ≤ VPDCUR(I,J))
Y
UPPER TOL. IN SPEC? (VPDTIL(I,J,2) ≥ VPDCUR(I,J))
Y
SEXDIS JUMP TO ERROR ROUTINE
RETURN FROM ERROR ROUTINE
IS PRESENT SENSOR READING EXACTLY = PREVIOUS SENSOR READING? (VPDCUR(I,J) = VPDLDV(I,J))
Y
F2
B2
Y
ADD 1 TO I
OUTER DO LOOP COMPLETE? (I = 20)
Y
ADD 1 TO J
INNER DO LOOP COMPLETE? (J = 4)
F2
SET VTBIT1(I,J) = 0
SDPRNT "DATE/TIME,I,J MAY BE OUT OF SERVICE"
Y
IS VPDIT2(I,J) = 360?
ADD 1 TO VTBIT2(I,J)

Figure 8.6 Cont.

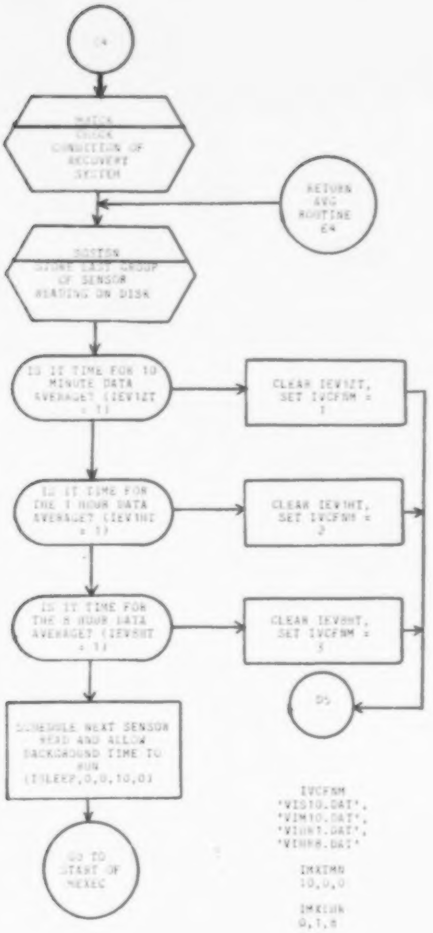
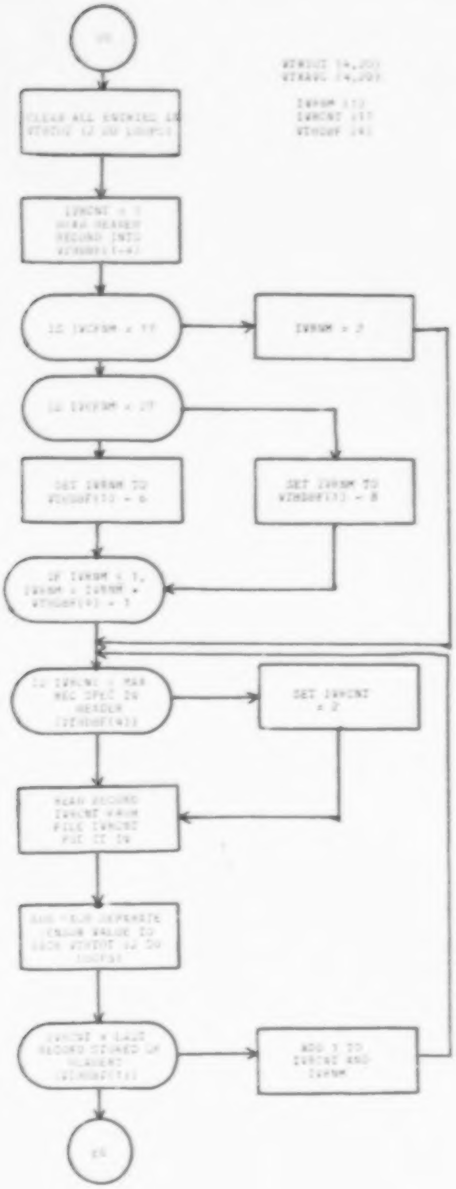

C4
WATCH
CHECK CONDITION OF RECOVERY SYSTEM
RETURN AVG ROUTINE E4
DSTDN
STORE LAST GROUP OF SENSOR READING ON DISK
IS IT TIME FOR 10 MINUTE DATA AVERAGE? (IEV1ZT = 1)
CLEAR IEV1ZT, SET IVCFNM = 1
IS IT TIME FOR THE 1 HOUR DATA AVERAGE? (IEV1HT = 1)
CLEAR IEV1HT, SET IVCFNM = 2
IS IT TIME FOR THE 8 HOUR DATA AVERAGE? (IEV8HT = 1)
CLEAR IEV8HT, SET IVCFNM = 3
D5
SCHEDULE NEXT SENSOR READ AND ALLOW BACKGROUND TIME TO RUN (ISLEEP,0,0,10,0)
GO TO START OF MEXEC
IVCFNM
'VIS10.DAT',
'VIM10.DAT',
'VIHR1.DAT',
'VIHR8.DAT'
IMXIMN
10,0,0
IMXIHR
0,1,8

Figure 8.6 Cont.



WTHOUT (4,20)
WTHAVG (4,20)
IWRNM (1)
IWMCNT (1)
WTHBUF (4)
CLEAR ALL ENTRIES IN WTHOUT (2 OR LOOPS)
IWMCNT = 1 READ HEADER RECORD INTO WTHBUF(1-4)
IS IWRNM = 1?
IWRNM = 2
IS IWRNM = 2?
SET IWRNM TO WTHBUF(3) - 6
SET IWRNM TO WTHBUF(3) - 8
IF IWRNM < 1, IWRNM = IWRNM + WTHBUF(4) - 1
IS IWMCNT > MAX REC SPEC IN HEADER (WTHBUF(4))
SET IWMCNT = 2
READ RECORD
ADD 1 TO IWMCNT AND IWRNM

Figure 8.6 Cont.

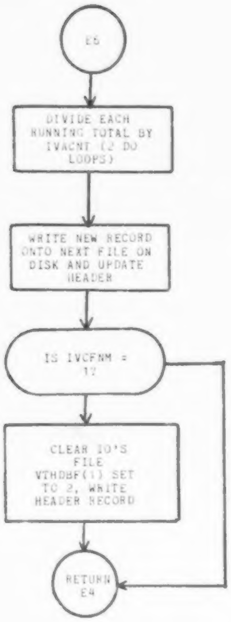
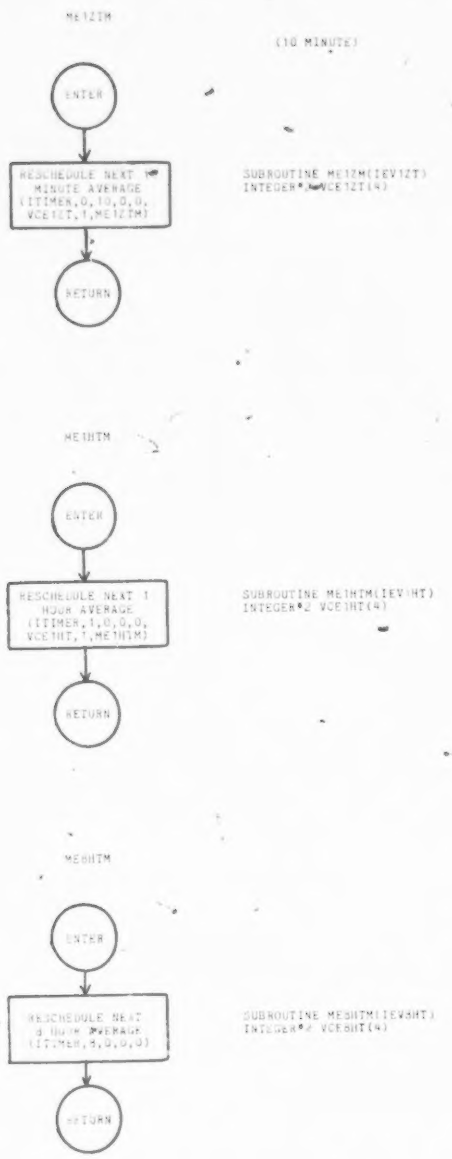

E6
DIVIDE EACH RUNNING TOTAL BY IVACNT (2 DO LOOPS)
WRITE NEW RECORD ONTO NEXT FILE ON DISK AND UPDATE HEADER
IS IVCFNM = 1?
CLEAR IO'S FILE VTHDBF(1) SET TO 2, WRITE HEADER RECORD
RETURN E4

Figure 8.6 Cont.



ME12TM
(10 MINUTE)
ENTER
RESCHEDULE NEXT 10 MINUTE AVERAGE (ITIMER,0,10,0,0, VCE12T,1,ME12TM)
RETURN
ME1HTM
ENTER
RESCHEDULE NEXT 1 HOUR AVERAGE (ITIMER,1,0,0,0, VCE1HT,1,ME1HTM)
RETURN
ME8HTM
ENTER
RESCHEDULE NEXT 8 HOUR AVERAGE (ITIMER,8,0,0,0)
RETURN

```
SUBROUTINE ME12M(IEV12T)
INTEGER*2 VCE12T(4)
```

```
SUBROUTINE ME1HTM(IEV1HT)
INTEGER*2 VCE1HT(4)
```

```
SUBROUTINE ME8HTM(IEV8HT)
INTEGER*2 VCE8HT(4)
```

Figure 8.6 Cont.

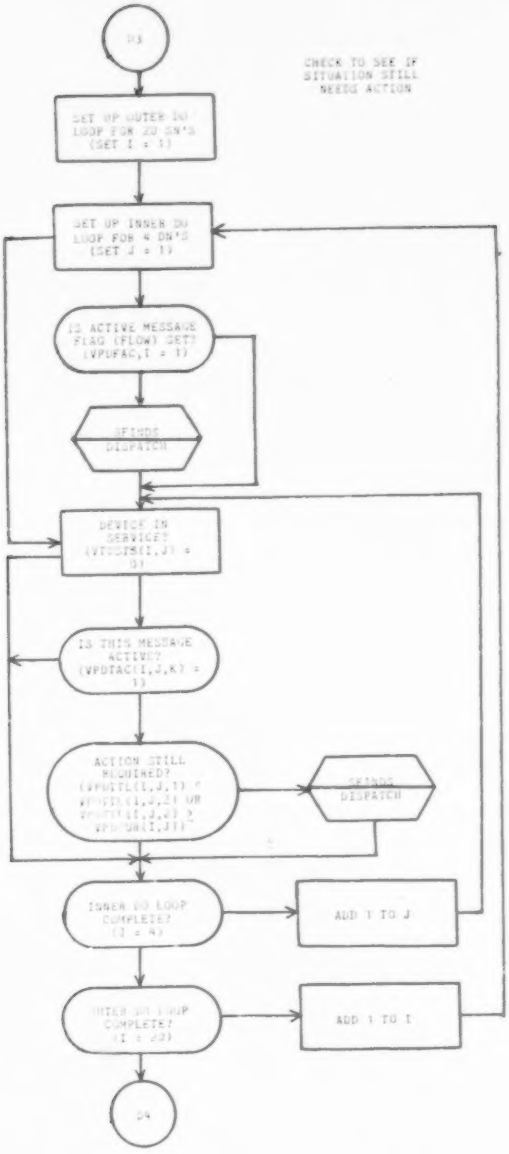

D3
CHECK TO SEE IF SITUATION STILL NEEDS ACTION
SET UP OUTER DO LOOP FOR 20 DN'S (SET I = 1)
SET UP INNER DO LOOP FOR 4 DN'S (SET J = 1)
IS ACTIVE MESSAGE FLAG (FLOW) SET? (VPUFAC,I = 1)
SFINDS DISPATCH
DEVICE IN SERVICE? (V[illegible](I,J) = 0)
IS THIS MESSAGE ACTIVE? (VPDTAC(I,J,K) = 1)
ACTION STILL REQUIRED? (VPUTTL(I,J,1) < VPUTTL(I,J,2) OR VPUTTL(I,J,2) > VPUPUB(I,J))
SFINDS DISPATCH
INNER DO LOOP COMPLETE? (J = 4)
ADD 1 TO J
OUTER DO LOOP COMPLETE? (I = 20)
ADD 1 TO I
D4

Figure 8.6 Cont.

brunt of the program design effort. In general, each point in the system which is being monitored will have an error analyzing routine. This is not to say that each sensor will have one error routine for itself because one point being monitored in the system will have more than one sensor with which it is associated. For example, error routines called by an out-of-tolerance conductivity reading will take flow into account and calculate lbs/day values for sodium (Na), Total Organic Carbon (TOC) and Total Dissolved Solids (TDS) at the digester, washer and No. 8 recovery sewers. If two sensors are used to monitor one point, and their readings are not related or cannot be evaluated jointly, separate error analyzing routines are written for each.

The general flow chart of an error analyzing routine is outlined in Figure 8.7. An error detected by any one sensor will cause the executive module to transfer program control to a routine specifically designed to evaluate the status of the situation. When the error has been analyzed, the appropriate actions are taken by the routine and program control is returned to the executive module. At the beginning of this routine, the procedure is to determine if the sensor which detected the problem is presently in service. If it is not, the routine is exited; if it is, further processing is continued. The confidence interval of the existing error condition is then checked. The confidence interval is merely to verify that the detected problem has existed long enough to warrant corrective action. The purpose of this is to prevent the system from being too sensitive to short term effluent variations. In a situation where immediate reaction is required; e.g., a high level in the spill tank, confidence interval checking is eliminated.

When the system has determined that a possible problem does exist, processing to evaluate and correct the situation is initiated. In this case,

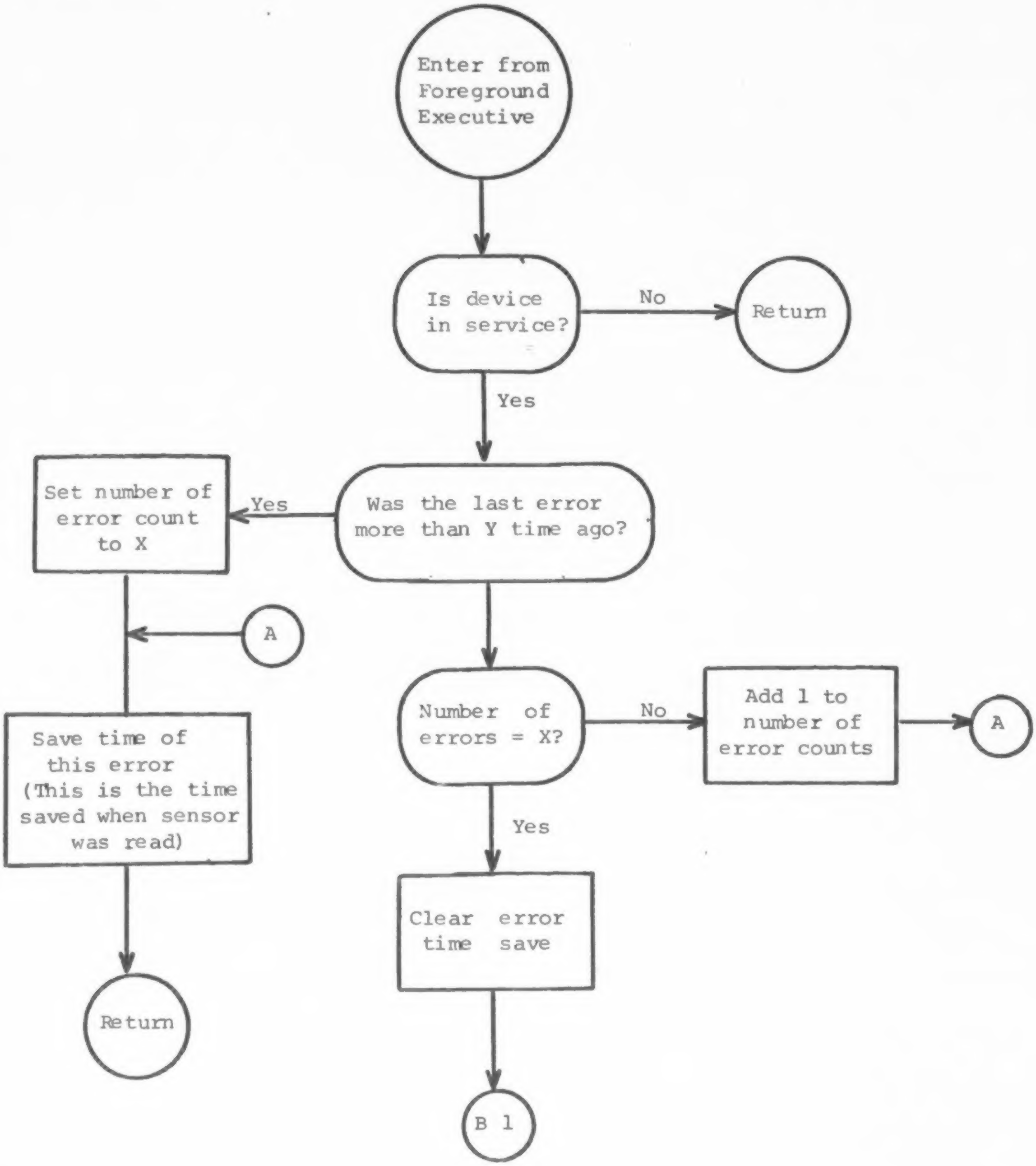

Enter from Foreground Executive
Is device in service?
No
Return
Yes
Was the last error more than Y time ago?
Yes
Set number of error count to X
A
Number of errors = X?
No
Add 1 to number of error counts
A
Yes
Save time of this error (This is the time saved when sensor was read)
Clear error time save
Return
B 1

Figure 8.7 General Structure of Error Analyzing Routines

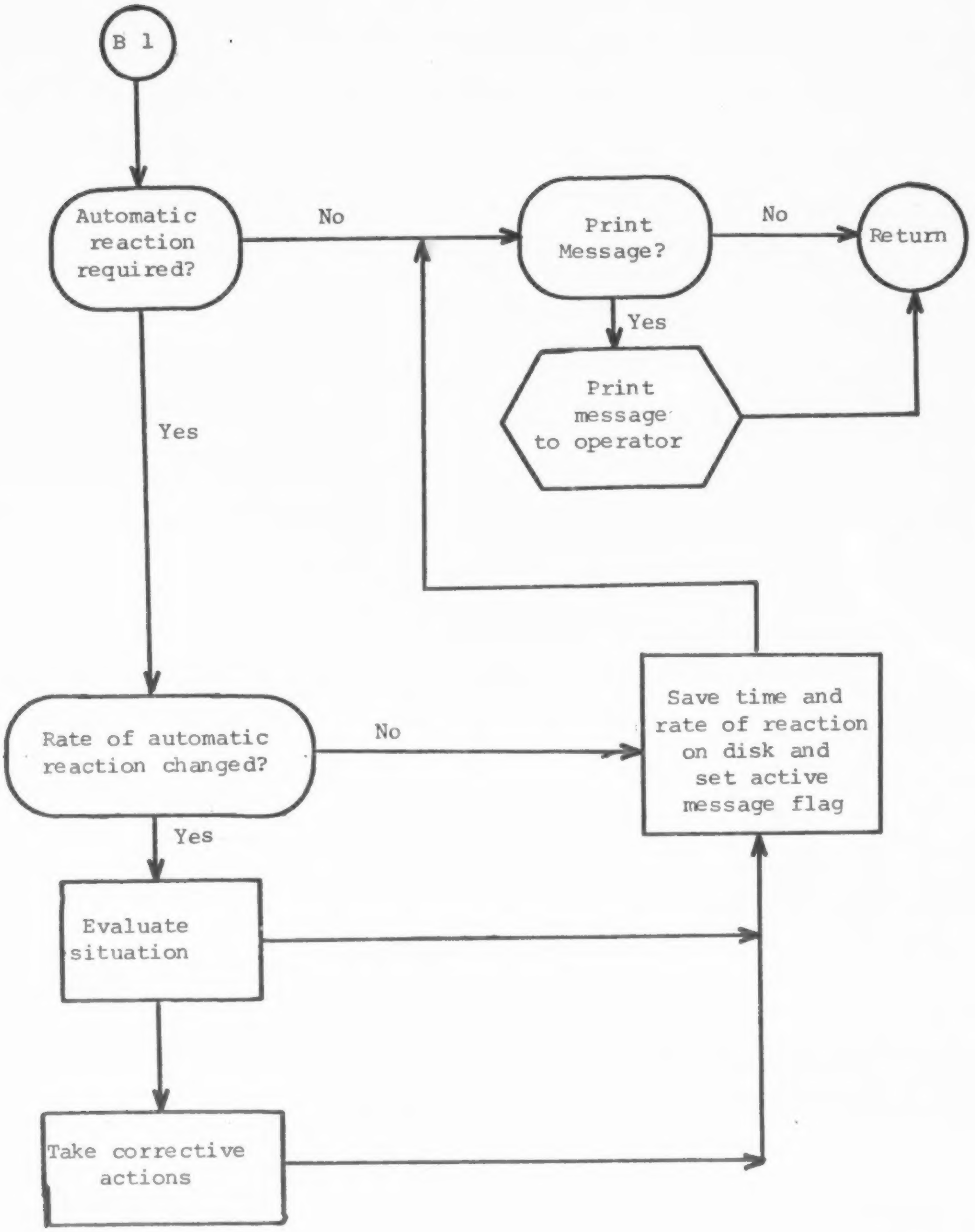

B 1
Automatic reaction required?
No
Print Message?
No
Return
Yes
Print message to operator
Yes
Rate of automatic reaction changed?
No
Save time and rate of reaction on disk and set active message flag
Yes
Evaluate situation
Take corrective actions

Figure 8.7 cont.

appropriate preventive measures are evaluated by the computer and corrective action is taken, either automatically or by instruction of the operator as to what alternate action should be taken, or both. In any case, the operator is kept informed of all problem conditions and their most likely cause and is also informed of any corrective actions taken. Any required corrective actions taken are noted (active message flag set) so that the foreground executive can continually check to see if the corrective actions are still required. Messages printed to the operator and time of the messages are stored on the system disk so that a complete log of system messages is always available.

Check Status of Ongoing Corrective Actions--The status of any presently existing corrective reactions to a problem situation is checked as part of the executive foreground program. This is done to insure that a problem situation is not being acted upon after the problem no longer exists. Current reaction procedures (flow diversion, pumping, etc.) are accounted for by setting an active message flag associated with that specific reaction. The flag is cleared when the problem is eliminated and the corrective reaction is no longer necessary.

Calculate and Store Average Sensor Values--Sensor values are stored by the system so that a history of these values is kept. Rather than store every sensor value read, the software calculates averages and stores these values. Ten minute, one hour and eight hour averages are provided. This data is available to the operator and to data analysis programs which are run in the background mode. When the foreground program has completed its processing, the computing time left before the next scheduled batch sensor read becomes available to the background programs.

System Layout and Referencing Scheme--Each point being monitored and output to in the spill control system at Brown Company is assigned a specific number pair. Table 8.3 is a matrix of number pair assignments. The first number of the pair refers to a station number (SN). A SN is assigned to each area which is being monitored and controlled. There are eleven SN's specified in Table 8.3. Total capacity of the system is twenty SN's. Associated with each SN is a device number (DN). The DN is assigned to a specified sensor or control device at each station. There are four DN's assigned to each SN specified in Table 8.3.

TABLE 8.3 STATION AND DEVICE ASSIGNMENT LOSS CONTROL SYSTEM

Station Number (SN)		DEVICE NUMBER (DN) 1	2	3	4
1	DIGESTER SUMP	CONDUCT	FLOW	PUMP	SAMPLER
2	BROWN STOCK WASHER SUMP	CONDUCT	FLOW	PUMP	SAMPLER
3	NO. 8 RECOVERY SUMP	CONDUCT	FLOW	PUMP	SAMPLER
4	MAIN KRAFT SEWER	CONDUCT	FLOW	--	SAMPLER
5	NO. 11 RECOVERY SUMP	CONDUCT	FLOW	PUMP	SAMPLER
6	CAUSTICIZING SEWER	CONDUCT	--	--	SAMPLER
7	TOTAL CAUSTIC SEWER	CONDUCT	FLOW	--	SAMPLER
10	200K GAL SPILL TANK	CONDUCT	LEVEL	PUMP	SAMPLER
11	200K GAL SPILL TANK VALVES	VALVE TO RECOVERY	VALVE TO SEWER	--	-
12	EXISTING OVERFLOW TANK	--	LEVEL	--	-
13	WEAK BLACK LIQUOR TANKS	--	LEVEL	--	-

Referencing a particular point in the spill control system requires a SN-DN number pair. For example, the SN-DN pair 1-1 (reference Table 8.3) would refer to the conductivity probe at the digester sump and 1-2 would refer to the flow meter for this same sump. SN-DN pair 2-1 would refer to the conductivity probe at the BSW sump and so on.

The software as well as all operator messages and commands use the SN-DN pair to reference points in the spill control system.

Background Jobs--The background jobs are programs which run when the RT-11 F/B monitor determines that the foreground program is idle. When no other background jobs are running, the RT-11 keyboard monitor (KMON) is waiting for an operator command. These commands are of two types, standard RT-11 system commands and commands to run other background jobs. The system commands are described in the RT-11 reference manuals. Applications programs which will run in the background are operator interface and data analysis programs.

Operator Interface--The operator has the option of communicating with the software program via the keyboard printer. The communication consists of the ability to ask the computer to monitor any sensor he selects and provide him with the resultant parameter readings. He may also issue control device orders from the keyboard printer via the computer. Under special conditions, the operator has the capability to change the tolerances of the parameters being monitored. Such tolerance alterations will require supervisory permission. The operator also has the option of entering standard types of information such as stream conditions or holding tank contents, or marking a monitoring station out of service. He is also able to request a printout of any messages printed during a time period he will specify as an input. Some of the background programs are described briefly here.

MMCP - Change Parameters--In order for the loss control computer system to be responsible to various changes in the mill environment, certain computer program operating parameter and tolerance values must be updated from time to time. Therefore, in order for the LCS to work properly, these parameters and tolerance values must be kept in tune with what is happening in the mill. This program is intended to provide the system operator with the ability to change system parameters on line and off line. The changes can be reflected in the system diskette file UNITS.DAT as well as in the main memory resident data base. This updating capability will allow the operator to make permanent changes to the system. If a change is to be considered temporary, the operator can so indicate and the parameter will be changed only in the main memory resident data base, leaving UNITS.DAT unchanged.

This is a program included as part of the operator interface. It is intended to be run in the background while the foreground executive is running. It can also be run in a "stand alone" mode without the foreground program running.

Upon program entry, an introductory message is typed out. Initialization is performed, and the contents of the data file UNITS.DAT are read into the main memory storage area. The program then asks for and accepts a command string from the console. A table search for the command name given is then performed. If the name is not found, the user is informed of the error and the program loops back for more input. If the name was found in the command name table, control is passed to the appropriate command processing routine. Upon return from the routine, the program loops back for more input. Commands are available to read or change tolerance parameters, check or change the status of control devices, set or read coefficients of the correlation equations, set or read mass setpoints for sodium, TOC and total solids and set or read average values for the three parameters and flow.

MMSG - Read Back Operator's Message Log--The function of this program module is to provide the system operator with the ability to review messages sent by the Executive through the console. In the process of monitoring and controlling the loss control system, the foreground program prints messages to inform the operator of various events as they happen in the system. All messages output by the foreground program are stored and can be recalled using the program MMSG. The program allows the operator to selectively review the performance of a particular monitoring/control station. It also enables him to review a particular activity undertaken by the system; e.g., all diversions to a holding tank. This would allow the operator to easily review the day's events that may have occurred during off-shift periods. MMSG is a self-contained program designed to run in the background and is included as part of the operator's interface. It refers to the diskette file VMLOG.DAT as a read only file. MMSG can run with or without the foreground present as it does not refer to the common data base in any way. The message format is described in the Operator's Manual, Appendix C.

Table 8.4 is an example of the type of messages generated during operation of the system. These messages are printed at the keyboard printer as they are generated and are stored in the message file for later review. The date is not printed since the message is printed as it is generated. The stored messages would, however, be dated.

The messages printed here cover a period of operation of approximately ten hours. Time is shown in the first column; the type of message in the second column (refer to Table D.1 Appendix C); the station number and device

TABLE 8.4 MESSAGES GENERATED BY LCS SYSTEM OPERATION

```
10:47:32 SW 12- 2 May be out of service, it should be checked
11:09:33 SW 13- 2 May be out of service, it should be checked
11:43:12 SE  4- 0 Na OFF, No source
11:43:12 SE  4- 0 TOC OFF, No source
11:43:12 SW  4- 0 TS OFF, No source
11:45:09 SW 10- 2 May be out of service, it should be checked
11:48:27 AE  4- 0 All Na sources accounted for
11:48:27 AE  4- 0 All TOC sources accounted for
11:48:27 AE  4- 0 All TS sources accounted for
11:59:17 AA  1- 3 ON,    43.84 hrs. until HT is full
11:59:17 SE  1- 1 Na  Load from process=  1217 lbs/day
11:59:17 SE  1- 1 TOC Load from process=  2249 lbs/day
11:59:17 SE  1- 1 TS  Load from process=  7875 lbs/day
12:09:40 SE  1- 0 Flow/Cond Relation   24.2% change
12:09:40 SE  1- 1 Na  Load from process=  1643 lbs/day
12:09:40 SE  1- 1 TOC Load from process=  3087 lbs/day
12:09:40 SE  1- 1 TS  Load from process= 10734 lbs/day
13:21:51 SE  1- 0 Flow/Cond Relation  -37.6% change
13:21:51 SE  1- 1 Na  Load from process=  1182 lbs/day
13:21:51 SE  1- 1 TOC Load from process=  2204 lbs/day
13:21:51 SE  1- 1 TS  Load from process=  7687 lbs/day
13:40:44 SE  1- 0 Flow/Cond Relation  -40.1% change
13:40:44 SE  1- 1 Na  Load from process=   827 lbs/day
13:40:44 SE  1- 1 TOC Load from process=  1521 lbs/day
13:44:44 SE  1- 1 TS  Load from process=  5337 lbs/day
14:19:38 AA  1- 1 Na  Back in tolerance
14:21:12 AA  1- 1 TOC Back in tolerance
14:21:12 AA  1- 1 TS  Back in tolerance
14:21:12 AA  1- 3 Pump OFF
15:46:22 SW 10- 2 May be out of service, it should be checked
15:49:55 SE  4- 0 Na OFF, No source
15:49:55 SE  4- 0 TOC OFF, No source
15:49:55 SE  4- 0 TS OFF, No source
15:52:42 AA  1- 3 ON,    12.75 hrs. until HT is full
15:52:42 SE  1- 1 Na  Load from process= 13362 lbs/day
15:52:42 SE  1- 1 TOC Load from process= 24788 lbs/day
15:52:42 SE  1- 1 TS  Load from process= 86638 lbs/day
15:52:42 SE  1- 1 Na  Load to sewer=  8709 lbs/day.  Possible problem
15:52:42 SE  1- 1 TOC Load to sewer= 16157 lbs/day.  Possible problem
15:52:42 SE  1- 1 TS  Load to sewer= 56471 lbs/day.  Possible problem
15:57:56 AE  4- 0 All Na sources accounted for
15:57:56 AE  4- 0 All TOC sources accounted for
15:57:56 AE  4- 0 All TS sources accounted for
17:14:53 SE  1- 0 Flow/Cond Relation   22.2% change
17:14:53 SE  1- 1 Na  Load from process= 17410 lbs/day
17:14:53 SE  1- 1 TOC Load from process= 32625 lbs/day
17:14:53 SE  1- 1 TS  Load from process=113544 lbs/day
17:14:53 SE  1- 1 Na  Load to sewer= 11339 lbs/day.  Possible problem
17:14:53 SE  1- 1 TOC Load to sewer= 21249 lbs/day.  Possilbe problem
17:14:53 SE  1- 1 TS  Load to sewer= 73954 lbs/day.  Possible problem
```

TABLE 8.4 Cont.

```
21:22:26 AA  1- 1 Na   Back in tolerance
21:22:26 AA  1- 1 TOC  Back in tolerance
21:22:26 AA  1- 1 TS   Back in tolerance
21:22:26 AA  1- 3 Pump OFF
21:27:54 AA  2- 3 ON,   11.95 hrs. until HT is full
21:27:54 SE  2- 1 Na  Load from process= 19241 lbs/day
21:27:54 SE  2- 1 TOC Load from process= 36219 lbs/day
21:27:54 SE  2- 1 TS  Load from process=125815 lbs/day
21:27:54 SE  2- 1 Na  Load to sewer= 12208 lbs/day.  Possible Problem
21:27:54 SE  2- 1 TOC Load to sewer=22981 lbs/day.   Possible Problem
21:27:54 SE  2- 1 TS  Load to sewer=79830 lbs/day.   Possible problem
22:06:06 SE  2- 0 Flow/Cond Relation  -42.0% change
22:06:06 SE  2- 1 Na  Load from process= 13289 lbs/day
22:06:06 SE  2- 1 TOC Load from process= 24655 lbs/day
22:06:06 SE  2- 1 TS  Load from process= 86169 lbs/day
22:06:06 SE  2- 1 Na  Load to sewer=  8622 lbs/day.  Possible problem
22:06:06 SE  2- 1 TOC Load to sewer= 15998 lbs/day.  Possible problem
22:06:06 SE  2- 1 TS  Load to sewer= 55913 lbs/day.  Possible problem
06:08:49 AA  2- 1 TOC  Back in tolerance
07:33:08 AA  2- 1 TS   Back in tolerance
07:41:27 AA  2- 1 Na   Back in tolerance
07:41:27 AA  2- 3 Pump OFF
13:40:27 SE  1- 2 Hydraulic problem
13:43:33 SE  5- 1  Above set point
13:47:47 AA  1- 3 ON,    5.92 hrs. until HT is full
13:47:47 SE  1- 1 Na  Load from process= 20370 lbs/day
13:47:47 SE  1- 1 TOC Load from process= 38367 lbs/day
13:47:47 SE  1- 1 TS  Load from process=133244 lbs/day
13:47:47 SE  1- 1 Na  Load to sewer= 13187 lbs/day.  Possible problem
13:47:47 SE  1- 1 TOC Load to sewer= 24838 lbs/day.  Possible problem
13:47:47 SE  1- 1 TS  Load to sewer= 86260 lbs/day.  Possible problem
13:51:49 SW  5- 1  Back within set point
15:54:09 SE  1- 0 Flow/Cond Relation  -42.7% change
15:54:09 SE  1- 1 Na  Load from process= 10297 lbs/day
15:54:09 SE  1- 1 TOC Load from process= 18889 lbs/day
15:54:09 SE  1- 1 TS  Load from process= 66333 lbs/day
15:54:09 SE  1- 1 Ns  Load to sewer=  6593 lbs/day.  Possible problem
15:54:09 SE  1- 1 TOC Load to sewer= 12094 lbs/day.  Possible problem
15:54:09 SE  1- 1 TS  Load to sewer= 42472 lbs/day.  Possible problem
16:04:03 SE  5- 1  Above set point
16:13:02 SW  5- 1  Back within set point
17:32:51 AA  1- 1 TOC  Back in tolerance
18:20:57 AA  1- 1 TS   Back in tolerance
19:04:04 AA  1- 1 Na   Back in tolerance
19:04:04 AA  1- 3 Pump OFF
22:37:54 AA 11- 1 Pump to recovery OFF--Can't handle load
```

number (refer to Table 8.3), where the particular type of activity is generating the message in the third column; and finally, the message, some explanation of which is given below.

The first two messages are generated as a result of confidence interval checks and refer to the levels in the spill tank and weak black liquor tanks, respectively. They indicate that the levels have not changed over the confidence interval time and thus the sensors may not be functioning. Normal operation at the mill maintains the weak black liquor storage at a relatively constant volume so that this message for 13-2 is an indication of normal liquor handling. Similarly, the message for 10-2 below indicates that the level in the overflow tank is being maintained constant. Thus, the messages for 12-2 would indicate that either the sensor is faulty, material is going into and out of the spill tank at the same rate, or nothing is going into and out of the spill tank.

The six messages for SN 4 (4-0) indicate that the sensed values of the three parameters have gone above a specified average expected value and the source for these high values is not one of the monitored stations but some other tributary sewer. Five minutes later, the values return to average or below.

At 11:59, the pump at SN 3 came on, pumping to the spill tank and the present loads from the process were computed from the conductivity correlation equations and flow. Ten minutes later, the computed loads increased by 24% and stayed at a high level for over an hour, at which time they decreased until they finally came back within their tolerance levels at 2:21 p.m. (14:21) and the pump went off. Note that the pump did not go off until all three parameters were within their predefined tolerance range.

The pump at SN 1 came back on at 15:52 when that sump received a very high load, part of which could not be intercepted by the pump. Thus, a large portion continued on to the sewer and it is indicated that this load may cause a problem downstream at the wastewater treatment plant. The problem continued until 21:22, at which time the parameters came back within tolerance and the pump went off.

A short while later, a similar problem occurred at SN 2 and lasted until 07:41 the next morning. Nothing untoward then occurred until afternoon, at which time SN 1 received a high flow volume.

At 13:43, the conductivity setpoint at SN 5 was exceeded. Since flow was not being measured at that sump, no loads were computed, and since the pump was on analog control, no other indication that the pump was on was given.

During the same time interval, the setpoints at SN 1 were exceeded and only part of that load could be intercepted since the flow was greater than the pump capacity. This condition continued until 19:04 when all three parameters came back in tolerance and the pump went off.

Finally at 22:37, the recovery pump was shut off because the level in the existing overflow tank had exceeded its setpoint, i.e., it is getting full, and it can no longer receive flow from the spill tank.

The foregoing messages exemplify the types of activity occurring within a typical kraft pulping and recovery operation, and demonstrates the application of various setpoints and tolerance parameters used to initiate automatic and operator oriented responses to abnormal losses of process materials.

MMPB - Program to Play Back Data Files--This program is intended to provide the system operator with the ability to type out specified portions of the sensor data files and pump data files. The program allows the operator to specify start and finish times for the output records to fall between. Also, depending on the file requested, it will prompt for specific selection criteria, such as station number or device number. The selection criteria will be used to further restrict the output.

TABLE 8.5 FILE NUMBER SPECIFICATIONS FOR MMPB

File Number	File Name	Description
1	VIS10.DAT	10 second readings of all SN,DN Data (length = 100* or approximately 17 min.)
2	VIM10.DAT	10 minute average of all SN,DN Data (length = 145 or approximately 1 day)
3	VIHR1.DAT	Hourly averages of all SN,DN Data (length = 121 or approximately 5 days)
4	VIHR8.DAT	8 hour averages of all SN,DN Data (length = 91 or approximately 30 days)
5	VITP1.DAY	Date/Time ON and Date/Time OFF for SN#1 pump to spill tank (length = 150)
6	VITP2.DAT	Date/Time ON and Date/Time OFF for SN#2 pump to spill tank (length = 150)
7	VITP3.DAT	Date/Time ON and Date/Time OFF for SN#3 pump to spill tank (length = 150)
8	VITP4.DAT	Date/Time ON and Date/Time OFF for SN#5 pump to spill tank (length = 150)
9	VITHTR.DAT	Date/Time ON and Date/Time OFF the spill tank was pumped to recovery
10	VITHTS.DAT	Date/Time ON and Date/Time OFF the spill tank was pumped to the sewer

* The number following the length refers to the number groups of all SN,DN pairs in the system that can be stored in the file. When the end of the file is reached, the file loops back on itself causing the oldest data to be overwritten.

This is a program included as part of the operator's interface. It is intended to be run in the background while the foreground executive is running. It can run independently, however. It references the sensor data and pump time files as specified by the operator and so they must be accessible on device DX while the program is running. There are two types of files: sensor data average files and pump on/off files. A list and description of these files is presented in Table 8.5.

MMOUT - Output to Specific Device--This routine is to be run in the background as an operator interface program. If the operator wants a pump or valve ON or OFF and does not want the system to override this action, he must mark that device out of service using the MMCP STAT command. The operator can then output a 1 or 0 to turn the device on or off and the program will verify that the output has been sent.

SYSTEM OPERATION

General Operation

The spill control system at Brown Co. has been in operation for over two years and has operated both in the analog control mode and in the direct digital control mode during that time. All material that has been sent to the spill tank has been returned to the chemical recovery system; none has been sent to the sewer with one exception when it was necessary to enter the tank during a shutdown and the lower few feet of the tank contents below the pump suction was drained to the sewer.

On very few occasions has the spill tank been more than 50% full and it has generally been less than 20% full due to the operating philosophy of returning material to the chemical recovery system whenever possible. In addition to storing intercepted spills during normal day to day mill operation, the spill tank has also served as extra weak black liquor (WBL) storage during periods of high liquor inventory due to evaporator or recovery shutdown or scheduled mill shutdowns. It was during those periods that the spill tank was more than 50% full. Use of the tank for WBL storage requires supervisory permission and involves manual operation of a valve.

During a representative 18 day operating period, the system intercepted 897,000 gallons from the sumps and returned this volume to the chemical recovery system. This volume contained about 25,000 lbs of sodium (Na), 30,000 lbs of BOD and 135,000 lbs of dissolved solids and the loss control system prevented these materials from going to the sewer.

During the period that the loss control system has been in operation, the computer availability has been very close to 100%. Total system availability has been 85 to 90% with the external hardware; i.e., sensors, transmitters and wiring being responsible for the downtime.

Operation of Intercept and Storage System

Sumps--

The sumps utilized to intercept spills were existing in the mill sewer system prior to installation of the loss control system and were thus not designed for the loss control system. As a consequence, they are undersized for this purpose and allow the pumps to run dry when inflow to the sump during a spill is less than pump capacity. The sewers leading to the sumps were also pre-existing and were not amenable to accepting a variety of flow measuring devices. In fact, in one it was physically impossible to install any flow measuring device. Consequently, in the other three sumps' inlet sewers, rectangular weirs were employed as the primary flow measuring device with an upstream measurement of head on the weir serving as the signal used to compute flow in gpm. The measurement was accomplished utilizing an admittance type sensor.

Pumps--

The pump characteristics were given previously in Table 8.1. The sump pumps and the spill tank recovery pump are Gormann-Rupp self priming, open impeller pumps. They presented no particular problems and served their function adequately even though they frequently pumped dry, as noted above. They could probably have been of lower capacity although the magnitude and frequency of spills was greater prior to the installation of the loss control system and best estimates then of the required pump capacity resulted in the procurement of the present pumps.

Liquor Diversion--

As noted previously, weak black liquor can be stored in the spill tank when it is desirable to do so. This is accomplished via a connection between a weak black liquor pipe and the pipe leading from the sumps to the spill tank. The connection has a manually operated locked gate valve to allow the transfer with supervisory permission. The liquor is then returned to the chemical recovery system in the same manner as spills; i.e., via the existing overflow tank, the vats of the washers and the washer filtrate tanks. The use of the spill tank for this purpose has a beneficial effect in that liquor losses can be curtailed or minimized during scheduled or, particularly, unscheduled equipment shutdowns.

Piping--

The physical aspects of the spill interception and recovery piping have been described previously. The portion of the piping which is outside and above ground froze during the winter months necessitating the installation of insulation. No other problems with the piping were encountered.

Spill Tank--

The spill tank was described previously and is shown schematically in Figure 8.2. With the exception of the one previously noted incident when it was necessary to enter the tank to remove some accumulated solids, no particular problems have been encountered in the operation of the spill tank. Foaming in the tank, at the pump or in the return flow has not been noted. The tank contents are recirculated within the tank when the pump is on and material has always been returned to the chemical recovery system thus keeping the spill tank level very low. It was originally intended to use the spill tank as a concentrator as explained in Section 6; i.e., when the spill tank is nearly full, materials in the spill tank would be pumped to the sewer to make room for the more concentrated material. Although software is available to accomplish this, it was never utilized since it was always possible to return the spill tank contents to the chemical recovery system. The only times that the spill tank could not be pumped to recovery were when the level in the existing overflow tank or in the weak black liquor tanks exceeded their setpoints. At those times, the spill tank still had sufficient capacity so that it was possible to continue intercepting spills and it was unnecessary to pump the spill tank to the sewer. Thus, during normal operation of the loss control system, the spill tank was operated at a low volume of intercepted material which was a prime objective of the loss control strategy.

Operation of Return System

Although the design of the loss control system and the operation of the loss control strategy allowed for pumping collected spills from the spill tank to the sewer and thus the wastewater treatment plant at a controlled rate, this option has never been exercised. Instead, the collected spills have always been pumped to the chemical recovery system via the existing overflow tank, which itself collects spills from the brown stock washer area above. Those spills are routed through the floor drains to the overflow tank. These area spills are then pumped to the feeder vats of the first stage of the washer for stock dilution. Although the overflow tank pumps have a total capacity of 1300 gpm, the long term rate of pumping from the overflow tank is approximately 225 gpm. The long term average rate for pumping from the spill tank is 20 to 30 gpm or approximately 10% of the overflow tank pumping rate. When material is pumped from the spill tank to the overflow tank, the rate varies from 80 - 120 gpm due to the head loss through the control valve (SN 11) as the valve is not fully opened. The washer operators desire that the rate be no more than this for purposes of their control of the brown stock washing process.

No adverse effects on the washing process have been attributed to return of collected spills from the spill tank. The material returned is similar in characteristics to the material collected in the overflow tank which has historically been pumped to the washers. The only adverse effect of this combined flow on the washers is a slight dilution of the weak black liquor by 0.5 to 1.0% but the evaporators have the capacity to handle this extra load. On the positive side, pumping the combined spills to the washer vats serves to filter out any fiber in these spills thus reclaiming spilled pulp.

Operation of Control System

Computer Hardware--

The computer and its peripherals and the sensor and control system interface (ICR) are covered by a maintenance contract with Digital Equipment Corporation. The contract provides for preventive maintenance at intervals of 90 days. The computer has been in use since early summer of 1977 for development and checking of software. Since late fall of 1977 has been in continuous use gathering data and controlling the spill recovery system. The routine maintenance of the computer and interface system has resulted in nearly 100% availability of that system and no major problems have been encountered attributable to the computer hardware.

In the period of operation, the computer and peripherals, including the ICR, have required ten service calls by a DEC technician in addition to the preventive maintenance. These involved replacement of printed circuit boards or their components in the ICR, replacement of the fan, printer circuit board and printing head on the keyboard printer and replacement of the disc drive three times. The downtime associated with these outages was generally less than two days during which time the spill system was on analog control.

The one deficiency of the control system as designed, is the lack of feedback from the controlled elements to the controller; i.e., the computer. When the computer sends a signal to open or close a valve or turn a pump on or off, there are no automatic means to check whether or not the action has been accomplished. For example, the pumps have three modes of operation; computer, analog, or manual, and if someone has placed the pump in the analog or manual modes or turned the power to the pump off, the computer is still able to send a signal to turn the pump on and it is assumed that the action has been taken. To get the feedback from each controlled element in the loss control system would require considerably more sensor hardware and wiring and more software and interface to deal with the analog signals. Because the present project is a research and demonstration effort and the strategies could be analyzed independent of this feedback system as discussed in Section 6, the necessary elements to obtain and manage this feedback were not included in the budget. However, incorporation of this feature in future loss control programs is highly recommended and desirable; and for any critical control element it is absolutely necessary.

Another feature which it would be desirable to have and which would have been of use in this project is the availability of more memory. Data storage in the computer was limited. In the case of the ten minute averages, only approximately 24 hours of this data file was retained by the system before the oldest data were written over by current data. Thus, the oldest data were lost unless they were printed out on the keyboard printer. This was not only an inconvenience in that an operator would have to be present to initiate the printout but also sacrificed some data which would be desirable for further off-line analysis of the system operation. The initiation of data file printout could have been accomplished automatically by additional software but the data would then not be in a useful form; i.e., it would be hard copy not in a form ready for further processing. The provision of external memory, such as a magnetic tape unit, would have allowed accumulation of system operation data but costs would increase and an objective was to keep costs in line with the benefits of the system. Also more hardware would have also required additional software to transfer the files to tape at predetermined intervals. It

8-44

was originally thought that the one hour and eight hour data average files would serve the purposes of additional data analysis and since they were retained by the system proportionally longer it would not be necessary to extract them on a frequent schedule. They also would not be in a convenient form and this wasn't anticipated until the system was actually operating at which time budget constraints precluded additional hardware as noted above.

External Hardware--

The operation of any control strategy or measurement process depends on the external hardware or sensors and the electrical connections from sensors to interface to obtain signals for conversion into meaningful data with which to operate the control system. The sensors are thus the most critical elements in the system and, being exposed to the harsh production process environment, are the elements of the system most prone to failure. Nevertheless, the total loss control system availability was 90%, i.e., downtime was 10% or one out of ten sensors may not be functioning at any one time. A review of the individual sensors follows.

Flowmeters--Flow in the process sewers was measured utilizing rectangular weirs installed in the existing rectangular cross section channels leading to the sumps. Weirs would not be the first choice for this application since solids can and did accumulate behind them. Although they were designed to be removable, they very soon became lodged in their supports and impossible to move. Other devices such as Parshall flumes or critical depth meters would be more appropriate but, mainly because of space availability, such devices could not be installed. Parshall flumes are utilized in the main sewers at SN's 4 and 7.

8.45

Head on all of the weirs and flumes was measured utilizing a sensor installed directly in the sewer whose principle of operation depends on a change of impedance with a change of liquid height on the sensor. These sensors were subject to physical damage rendering them out of operation for various periods. In addition they sometimes held a maximum charge producing a 50 ma signal indicating a false high flow. They also sensed heavy foam, when present, again indicating a false high flow. These sensors were checked when flow readings were suspect and calibrated as necessary.

Flow from the spill tank to the overflow tank was measured utilizing an ultrasonic sensor and meter with output to the computer. The sensor was fixed to the outside of the 4 inch diameter return piping at a low point in the piping to ensure that flow completely filled the pipe and the velocity of flow was detected. Appropriate conversion of the velocity signal to volumetric flowrate was made by the computer software. No difficulties with this sensor were experienced.

Conductivity--Solution conductivity was measured with standard temperature compensated industrial sensors and transmitters. As noted previously, conductivity was chosen as the parameter to be sensed to indicate the concentrations of the parameters of interest by correlation. Conductivity was chosen because it is a simple measurement; personnel at the mills are familiar with the instrumentation; the instrumentation is relatively simple, straightforward, reliable and inexpensive and conductivity is sensitive to changes in characteristics of pulp mill process streams. All of these attributes proved to be true and useful in this project. All that is necessary to keep this parameter reliable is routine maintenance and calibration and occasional reconfirmation or reestablishment of the correlation.

3 46

Conductivity probes in the system were checked on a weekly basis and recalibrated when there was an apparent error in the reading. The output was generally always within 200 umhos/cm of the true value.

Two electrodeless conductivity analyzers were also used during the course of the project and their performance was also good. As noted in Section 5, this type of analyzer is unaffected by material which coats the sensor and is particularly appropriate in the presence of abrasive material or material which may coat the sensor, such as in causticizing process sewers.

Liquid Level--Level in the spill tank, overflow tank and black liquor storage tanks was monitored utilizing standard differential pressure cells. These performed well and were never out of service.

Software--

The software and its functions have been described previously. The software used in the loss control strategy can be categorized in two ways; a) the purchased RT-11 operating system which handles the computer peripheral devices such as the real time clock, keyboard monitor, ICR etc. and allows the user to assemble software specific and unique to the task at hand and the user assembled software and b) the foreground software which operates on a priority basis reading sensors, gathering and storing data and printing messages and the background software which, for example, allows the operator to communicate with the system, change setpoints and obtain historical data files.

The majority of the software developed in this project was designed to operate in the forground mode and constitutes the applications and error analysis programs. The remaining software was designed to operate in the background mode to allow the operator to communicate with the system.

The software performed its functions adequately; that is, sensor analog signals were accepted, converted to digital, analyzed and summarized. If a situation was judged to be out of tolerance, the operator was notified and appropriate action was taken by sending a signal to a control device. The operator interface software allowed setpoints to be changed and messages and data to be retrieved.

Some changes were made to the software during the course of the project but these were, in general, minor changes. For example, the messages indicating that averages were being computed were eliminated as they did not have much significance. Messages indicating that a device may be out of service because it had not changed for some period of time were inhibited in the case of tank levels by assigning the maximum value to the confidence interval, tolerance parameter 3, since tank levels did not change very fast and, during normal process operation, the overflow tank level was maintained fairly constant by the operators thus generating this message frequently.

Linear Correlations--

As discussed previously, linear correlations were established relating sodium (Na), total organic carbon (TOC) and total dissolved solids (TDS) to conductivity. This was done so that the mass rates of flow of these economically valuable constituents could be computed and the decision as to whether or not there was a spill to be intercepted could be based on mass of material being lost.

These relationships were established prior to the startup of the loss control system. They were reconfirmed one year later and only minor changes had taken place in their slopes and intercepts. Since the reconfirmation, a few checks of the relationships were made and these were satisfactory. It had originally been intended to do more frequent reconfirmation of the relationships; for example, quarterly, and this would be a recommended procedure in a loss control program until a drift history can be developed.

The utility of the correlations is in the ability to quantify the amount of solids and sodium being recovered and the amount of BOD which is not going to the wastewater treatment plant. These quantities can be assigned monetary values as was done in Section 7 and the economic potential of the loss control system can be evaluated.

Major Events Causing Control System Action--

As an example of the types of occurrences which result in interceptible spills, the following chronology of major events is presented.

Date	Event
Feb. 3	Hoppers of recovery boiler washed
9	Dissolving tank pump leak
10	Carryover at one set of evaporators
15	WBL storage tanks overflowed
22	One washer filtrate tank drained
27	Problems with one washer line
28	Washing recovery boiler cyclone
Mar. 1	Sewered one washer
7	Carryover at one set of evaporators
8	Carryover at one set of evaporators
12	Overflow from recovery boiler scrubber
16	Stock pump leak

Mar. 16	One recovery boiler shut down
17	One washer line plugged
18	Draining line at one washer line
20	Wash liquor strainer at recovery boiler
26	Carryover at one set of evaporators
Apr. 8	Carryover at one set of evaporators
9	Overflow from one line of washers
12	One recovery boiler and partial
13	mill shutdown
19	Carryover at one set of evaporators
	Recovery boiler scrubber brine to sewer
23	Carryover at one set of evaporators
May 1	Floor washing in digester area
6	Foam tank overflow
	Heavy liquor spill at recovery boiler
13	Recovery boiler sump tank overflow

In addition to these short term events, one washer filtrate tank developed a leak that continued throughout the period until the scheduled partial mill shutdown on April 12 when it was repaired. The most frequent event above was carryover of black liquor to the evaporator condensate causing diversion of the condensate to the sewer thus resulting in a spill which is intercepted and pumped to the spill tank.

The above events are probably typical in the kraft pulping process. Events such as tank overflows, evaporator carryover, production process problems and washing of equipment are generally short term as they can

3.50

be corrected by operator action. Leaks of pumps, valves, and tanks are generally long term events as they may not be detected immediately and their repair takes some time and, as in the case of the filtrate tank leak, repair may not be possible unless the process is completely shut down. The latter is not done for economic reasons and since each process in the mill depends on the others. The loss control system prevents total loss of these materials and recycles them to the recovery process.

CONTROL SYSTEM RECOMMENDATIONS

Introduction

The loss control strategy and system discussed in this report is a research effort with the aim of demonstrating the applicability of such a strategy in a pulp mill and the applicability of direct digital control to such a system. As a research project, it utilized an existing spill control system at a host mill. The system was not designed specifically for the host mill but was adapted to the existing control system. In addition, the control system operated in only a portion of the mill which included the pulping, pulp washing and liquor recovery areas. However, the project as a whole evaluated existing spill detection and control systems in other mills and examined control strategies through simulation.

Hardware

Conventional Analog--

Conventional systems operate on analog control; i.e., an increase in concentration above a predetermined setpoint as detected by a conductivity analyzer triggers some action and when the conductivity falls below the setpoint, the action ceases. This results in on/off control and doesn't take into account the volume or mass of the spill. A large reservoir or spill tank is necessary to avoid overfilling of the spill tank or manual action by an operator is required to shut the spill interception system off if the tank is nearly full. This type of system is adequate if a large amount of storage is available and evaporator capacity is also available to process the intercepted material.

Computer Control--

Computer controlled systems are recommended in situations where storage volume is minimal or extra evaporator capacity is often unavailable. Such a system would allow various strategies such as concentrating in the spill tank or hold and release of weaker spills to wastewater treatment. Additionally, digital control could provide summaries of data and events occurring in the system and could be integrated with total mill sewer system monitoring. The control system could also be integrated with the wastewater treatment plant so that spills could be sent to treatment when extra capacity was available there and returned to process when treatment capacity was unavailable.

Sensors--

Flowmeters--Recommended flowmeters for open channel flow measurement are Parshall flumes or critical depth meters which do not present an obstruction to flow and are self-cleaning. Ultrasonic or magnetic flowmeters are recommended for flow in pipes as they also do not obstruct flow.

Conductivity--The conventional conductivity sensor with electrodes manufactured for industrial service and a transmitter with temperature compensation, selectable ranges, standard voltage or current output and setpoint availability as used in this project are recommended. Electrodeless sensors would appear to be the choice for extremely severe service such as in sewers carrying ablative or scaling material.

Other Parameters--Sensors are commercially available to monitor other parameters but, as discussed in Section 5, they have various drawbacks, particularly high cost and difficult sampling problems. Their use in a loss control monitoring program for the chemical pulping industry is not recommended.

Software--The amount of software in the system is a function of the needs and desires of the organization developing the system and the amount of money which can be allocated to software development. In the present project, approximately two man-years was invested in software development but this included the initial conceptualization of the strategy and, it is hoped, this effort will serve as a base and model for similar strategies thus reducing software costs. The minimum recommended software would involve the applications programs for each station and device in the system and programs to output the times, durations and magnitudes of spills, the condition of each device and the spill tank inventory. Software to summarize data for review by appropriate personnel would be a recommended option.

Parameter Correlations--Use of correlation equations relating the parameters of interest to conductivity is recommended. The relationships should be checked bimonthly using three samples representing the extremes and midpoint of the regression line and should be reconfirmed annually and when a major process change has occurred.